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THE GLANDS OF THE ANAL CANAL IN MAN

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Interest in the existence and function of the glands of the anal region of man has existed for a long time. Today there are almost no differences of opinion about the glands located in the circumanal area. Less consistent are the investigative results on the glands of the anal canal proper, particularly those of the zona columnaris. Some authors deny glands in this area completely; others find them only occasionally; still others cannot decide whether they are glands or just epithelial lined spaces, whereas some authors refer to them as true glands with permanent secretion. Interest in the anal canal glands is increasing because of the assumption that they play a definite role in the genesis of some ano-rectal diseases, lesions, and even malignant tumors.

The present study of this region was undertaken to verify or disprove certain statements relating to the existence, individual variation, position, number, type, course, and possible significance of these glands. Another motivating factor for this investigation was whether the glands of the anal canal in man have a definite function or whether they are vestigial remains.

REVIEW OF THE LITERATURE

It is well-known that the anal region of animals, particularly the mammals, is rich in different glands. According to their openings they are called rectal, proctodeal, paraproctic, anal, or circumanal glands. Most of them are modified skin glands. However, some animals possess in this area specific glands, which can be monoptyche or polyptiche; eccrine, apocrine, holocrine or meroholocrine secreting. In the animal kingdom these specific or modified skin glands are so different in position, arrangement, structure and function, that even closely related species may show variations. The secretion of most of the glands plays an important role in the sexual life of the animals, whereas the secretion of others are designated for identification of species or sex, and still others produce odoriferous or poisonous substances for defense or offense.

In man, the area just outside the anal orifice, the immediate neighborhood of the anus, is known as the circumanal or perianal skin. Here are located the so-called circumanal glands which are large sebaceous glands associated with hairs, and the sweat glands. Some of the latter are of the apocrine type and even larger than those of the axillary region (Gay, 1871; Szent-Györgyi, 1913; Schaffer, 1924; Hamperl, 1925; Patzelt, 1931, 1936; Sperling, 1935; Peter and Horn, 1935; Kratzer and Dockerty, 1947).

The zona cutanea of the anal canal is characterized by Johnson (1914) as being lined with stratified squamous distinctly hornified epithelium, with numerous papillae, hair follicles and sebaceous glands. Schaffer (1924), Hamperl (1925) and Patzelt (1931, 1936) describe sebaceous, sweat and large apocrine glands as being common in this zone, just as they are in the circumanal region. Kirkman (1951), however, has seen a few modified "sudoriparous" glands only in the very distal part of the cutaneous zone, whereas Gay (1871) in this area found only sebaceous glands.

The zona intermedia of the anal canal seems to be poor in glands. Robin and Cadiat (1874) emphasize that this zone is lacking entirely in hairs and glands, whereas Koelliker (1850), Romiti (1899), Braun (1901), Stieda (1902), and Johnson (1914) did observe a few sebace-

ous glands in some individuals but never any hairs in this zone. Szent-Gyõrgyi (1913) and Hamperl (1925), however, have shown that in the zona intermedia are found both types of sebaceous glands: "free" and those attached to the hair follicles. Hamperl states that the free sebaceous glands are very rare, but Szent-Gyõrgyi found them in about 50 percent of the investigated material. Tucker and Hellwig (1933) and Tucker (1935) described the zona intermedia as being lined by "transitional epithelium" and the area from which "anal ducts" originate.

The main interest of investigators of this region has been and still is concentrated in the zona columnaris of the anal canal because of the peculiar glandlike structures found in this area. Generally these structures are called "anal glands" but they have many other names, almost as many names as there are authors who have investigated them. These structures are of investigative interest because they do not look like the other glands of the body and because they are of practical, clinical importance. Many years ago Morgagni (1719) described secondary grooves originating from the rectal sinuses and leading into wide cystlike cavities. Haller (1765) mentioned that large mucous glands open into the sinus rectales. To Herrmann (1880) and Herrmann and Desfosses (1880) we owe the first good description of these glandlike structures. They state that from the bottoms of the rectal sinuses irregular canals or slitlike spaces extend into the submucosa, some of them showing sacklike dilatations. The latter authors call them secondary type Morgagni sinuses. From these dilatations branch off tertiary "sinuses" in the form of simple or branched tubules. Some of these terminal tubules penetrate the internal sphincter muscle. These third type of tubules and the dilatations are supposed to be quite similar to glands. Herrmann (1880) and Herrmann and Desfosses (1880) called them "special acinous glands" or "intramuscular sinuses." However, these investigators were not certain whether these structures should be classified as glands or not because they were not able to find any secretory characteristics in them. Braun (1901) has seen Herrmann's (1880) "secondary sinuses" but could not find the "special acinous glands" or "intramuscular sinuses" and therefore denied their presence. Szent-Gyõrgyi (1913) is also of the opinion that these channels are not glands but recesses of the mucosa whose terminal ends are dilated. But only a year later, Johnson (1914) demonstrated, in the zona columnaris area, the existence of what he calls "anal ducts" and "anal glands" in human embryos in various stages of development. He describes them as simple tubules arising from the rectal sinuses. In some cases they extend only as far as the submucosa, while in others the gland enters the internal sphincter muscle and dilates in an ampullalike structure which he calls "intramuscular gland." He also states that it is claimed that the evidences of secretory cells are wanting in the adult although in his material (fetus and neonate) such cells are present. The first good information of the zona columnaris glands in the adult is provided by Hamperl (1925). In general the description of the glands resembles that given by Johnson (1914). Because these structures open into the proctodeum, Hamperl calls them "proctodeal glands." He characterized them as simple or branched tubular glands which terminate in the submucosa or pierce the muscle layers. Except for a few mucus secreting cells, he could not find any other secretory characteristics. Hamperl considered these glands as being rudimentary. Petersen (1931) states that he could not find any secretory cells in these structures. Pope (1933) demonstrated acinuslike buds in them. As reported by Tucker and Hellwig (1933) and Tucker (1935), the "anal ducts" originate only from the zona intermedia. In man these ducts, according to these authors, are vestigial remnants. Also Gordon-Watson and Dodd (1935) consider the "anal glands" as vestigial structures which often lose their connection with the lumen of the anal canal because of the obliteration of the ducts during development. Morgan (1936) has observed that most of the "anal ducts" had their orifices in the posterior portion of the anal canal. Bremer (1936) noted the postnatal disappearance of secretory cells from the "anal ducts." As reported by Hill, Shryock and ReBell (1943), the "anal glands" only occasionally invade the internal sphincter muscle. They suggest the glands are not vestigial as some authors emphasize, but structures which function throughout life. Kratzer and Dockerty (1947) found "anal ducts" in about 50 percent of human anal canals. According to these authors the proximal parts of the ducts are lined by "transitional epithelium," the more distal ones by a double layer of cuboidal cells or even by simple squamous epithelium. Definite mucus producing cells may be demonstrated

in 10 percent of the tubules. Hill, Small, Hunt and Richards (1949) studied fetal material and found "anal glands" in 53 percent of the specimens. Kirkman (1951) who examined the ano-rectal regions of monkeys and adult humans, stated that he has seen anal ducts only occasionally.

MATERIAL AND METHODS

Material was obtained from five adults (2♀, 3♂), ages 22 to 28 years, and from two newborn infants (♀, ♂), four to five hours after death, with no history of disease in this area. All material was embedded in celloidin. Complete sagittal serial sections of each of the entire ano-rectal regions were prepared. Most of the sections were stained routinely with hematoxylin and eosin; only occasionally Heidenhain's Azan stain, mucicarmin and Bismarck brown were employed

OBSERVATIONS

The anal canal (pars analis recti) is the terminal portion of the large intestine (fig. 1). It begins where the rectum proper terminates (linea ano-rectalis) and it ends at the anal orifice (anus). Its length in the adult measures from 2.5 to 3.5 cm. In empty condition it presents the appearance of an anterior-posterior longitudinal slit. The upper part of the anal canal possesses six to ten permanent longitudinal folds of mucous membrane known as the rectal (anal) columns (columnae rectales Morgagni). At about 2 cm cranial to the anus each two adjacent columns are united by a semilunar fold. These little folds are the anal valves (valvulae semilunares) while the small fossae formed by them are known as the rectal or anal sinuses (sinus rectales). The sinuous or pectinate line formed by the margins of the anal valves and the corresponding portions of the intervening columns of Morgagni is known as the linea sinuosa analis.

Three zones can be distinguished in the anal canal: z. columnaris, z. intermedia, and z. cutanea. The proximal boundary of the z. columnaris is the linea ano-rectalis, a wavy line formed by the junction between the simple columnar epithelium with striated border of the rectal mucosa and the stratified epithelium of the z. columnaris. The distal boundary of this zone is the linea sinuosa analis. Zona intermedia is a transition zone between anal mucosa and the skin. It is bounded proximally by the linea sinuosa and distally by the linea ano-cutanea. The latter is rather an indistinct line formed by the junction of a thick stratified squamous non-keratinized epithelium of the z. intermedia and a thinner stratified squamous keratinized epithelium of the next zone. The z. cutanea of the anal canal is lined by stratified squamous keratinized epithelium and extends between the ano-cutaneous line and the anal orifice. Here, at the anus, the z. cutanea without demarcation passes over to the circumanal skin (fig. 1).

The main location of the glands of the anal canal is in a connective tissue zone between the sphincter ani muscles and the epithelial lining of the anal canal. In the anal region there are four different types of glands: (1) holocrine secreting sebaceous glands, (2) merocrine, eccrine secreting sweat glands, (3) merocrine, apocrine secreting scent-glands, and (4) specific zona columnaris eccrine glands.

1. Sebaceous glands.—Found mainly in the circumanal skin and in the z. cutanea of the anal canal. Less often they are seen in the z. intermedia and are never found in the z. columnaris. The circumanal sebaceous glands are the largest of the anal region. Even in the newborn they are strikingly large. They are richly branched and are all attached to hair follicles. They are numerous and not all are of the same size, the largest ones being located around the anus. Circumanal sebaceous glands differ from the common sebaceous glands of the skin only in being much larger and more branched. It has to be emphasized that the number and size of these glands vary considerably in individuals of the same age and sex. Sebaceous glands of the z. cutanea are smaller, however. They are less branched and limited to the subepithelial connective tissue. Each gland is associated with a short and thin hair follicle (fig. 3). Usually there are

many sebaceous glands in this zone, but there are also individuals with just a few small glands. In the z. intermedia the sebaceous glands are still smaller and not so common as in the previous areas. In this zone three kinds of holocrine secreting sebaceous glands occur: (1) with well-developed hairs, (2) with rudimentary hairs and (3) "free," "independent" or without hairs. The majority of the z. intermedia sebaceous glands are with rudimentary hairs and only a few glands are without hairs. The latter type is usually found in the cranial part of this zone. It has to be emphasized that in individuals with poorly developed circumanal and z. cutanea glands, the z. intermedia possesses sebaceous glands only occasionally (fig. 4).

2. Sweat glands (gl. sudoriferae).—Found only in the circumanal skin, lateral to the musculus sphincter ani externus. They were never seen in the wall of the anal canal. All of the material showed sweat glands in this area; even in the newborn they appear to be functional. In structure and location the secretory portions and the ducts resemble the usual sweat glands. In some individuals the glands look very well developed, the secretory portions forming large balls.

3. Apocrine glands or apocrine secreting scent glands.—In the anal region two types of apocrine secreting glands are seen: the common ones and the modified, respectively those of the circumanal skin and those located in the wall of the anal canal.

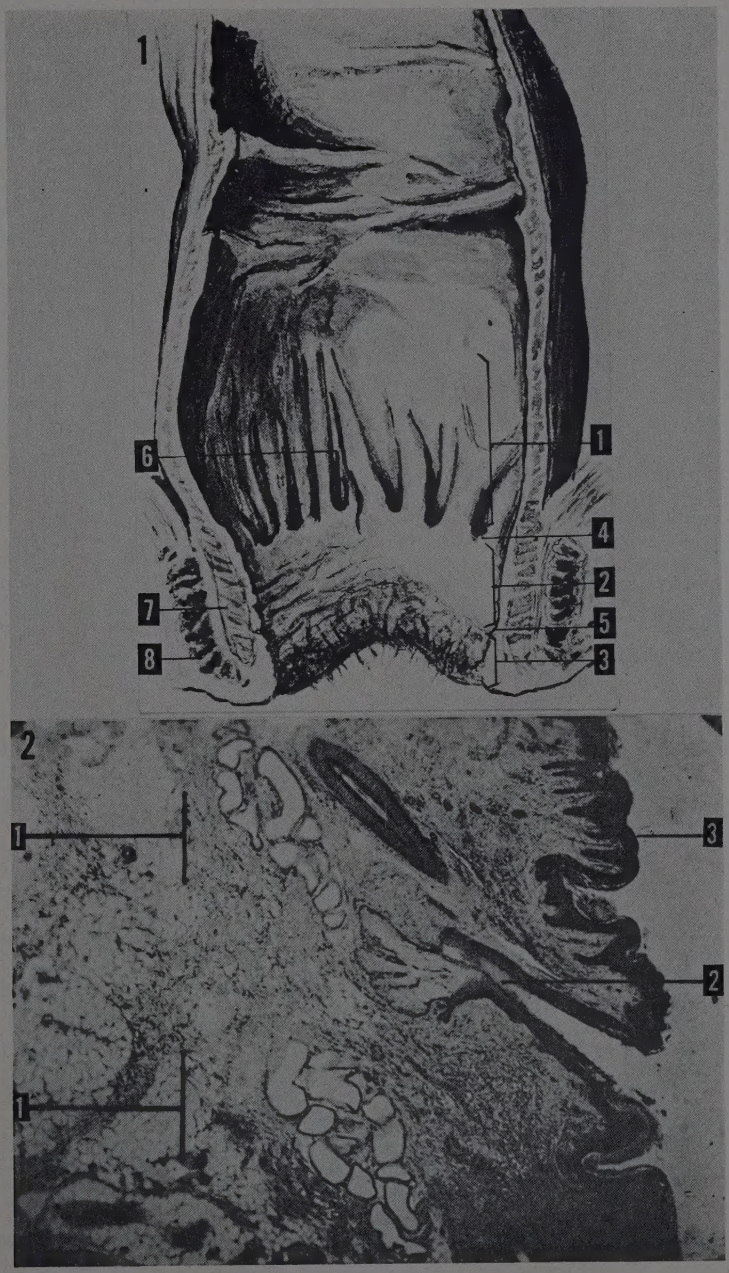
a) In the circumanal skin, in the vicinity of the anus, deep in the subcutaneous layer are located typical tubular apocrine secreting glands resembling those of the axilla. The secretory portions are twisted in loose balls, some of them measuring 3.6 to 4 mm in diameter. Lumina are large and the walls are composed of a single layer of cuboidal or columnar epithelial cells of the apocrine type. Between the glandular cells and the basement membrane are seen highly developed myoepithelial elements. The duct of the gland opens into the hair follicle above the orifice of the sebaceous gland. Not all individuals have the same number of glands; in our material it varies from 0 to 8. The average number of the circumanal apocrine scent glands is 4 to 5 and usually they are not located close to one another but are scattered (fig. 2).

b) In the z. cutanea, however, are seen modified apocrine glands. Craniad from the anus up to the z. intermedia, tubular glands of different length are seen. They are located in the connective tissue between the anal canal lining and the external sphincter muscle. The length and form of the tubules vary. The majority are 1 to 1.8 mm-long straight or tortuous tubules which open either into the duct of the sebaceous gland or independently into the anal canal. The latter condition obtains particularly in the more cranially located glands of this zone. Only on rare occasions is the terminal end of the tubule somewhat twisted. In each tubule a secretory and excretory portion can be distinguished. The secretory portion is lined with two layers of cells. The innermost cells are cuboidal and of the apocrine type while the outer ones are flattened and resemble myo-

EXPLANATION OF FIGURES IN PLATE I

FIGURE 1. The anal canal of man (semi-schematic drawing).
1. Zona columnaris
2. Zona intermedia
3. Zona cutanea
4. Linea sinuosa analis
5. Linea ano-cutanea
6. Sinus rectales Morgagni
7. Musc. sphincter ani int.
8. Musc. sphincter ani ext.

FIGURE 2. Apocrine secreting circumanal glands.
Transverse section of the anal region. 22-yr old ♂. ×30.
1. Secretory portion of the apocrine gland
2. Circumanal sebaceous gland
3. Epithelium of the circumanal skin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epithelial cells. Apparently they are very active glands because all the lumina are filled with fine granular secretion. Here and there around the glands are found more lymphocytes than is usual in the connective tissue. Approaching the lumen of the anal canal, the secretory portion passes over into the excretory duct with changes in the epithelium and the lumen. The tubule becomes slender, the epithelium thicker and consists of three cell layers which resembles stratified squamous epithelium. The lumen of the duct is very narrow scarcely visible.

The majority of the glands, then, are simple tubules of about uniform diameter such as have been described above and shown in figure 5. However, some remarkable variations occur. For instance, in addition to the described tubular form, occasionally are seen ampullalike forms where the secretory portion has a very wide (ca. 462 μ) lumen. Suddenly the secretory portion passes over into a very thin excretory duct lined with stratified squamous epithelium. The diameter of the duct is about 55 μ, that of the lumen 25 μ and the caliber does not change until the outlet is reached. In the ampullar part, the epithelium is similar to that described in the secretory portions of the tubular glands, only somewhat lower (fig. 6). From the appearance, structure, secretion and the orifices one can conclude that these structures are modified simple tubular, merocrine, apocrine secreting glands. In the present material, such glands are found only in four adults and in one newborn, averaging 13 to 17 in number. In the one remaining adult and one newborn we could not find any apocrine glands in the anal region, either common or modified.

4. Zona columnaris glands.—The lining epithelium of this zone is stratified. On the more elevated parts (columns of Morgagni) it is stratified squamous nonkeratinized, while in the depressions (between columns) which are not exposed to pressure and mechanical stress the epithelium is stratified columnar.

Three types of glands can be seen in this zone. Near the linea ano-rectalis are to be found a few intestinal glands of Lieberkühn and some goblet cells, whereas in the lower part of this zone are seen the orifices of specific, eccrine secreting glands. The latter ones are structures which most authors call the "anal glands" and which are the most interesting features of the zona columnaris.

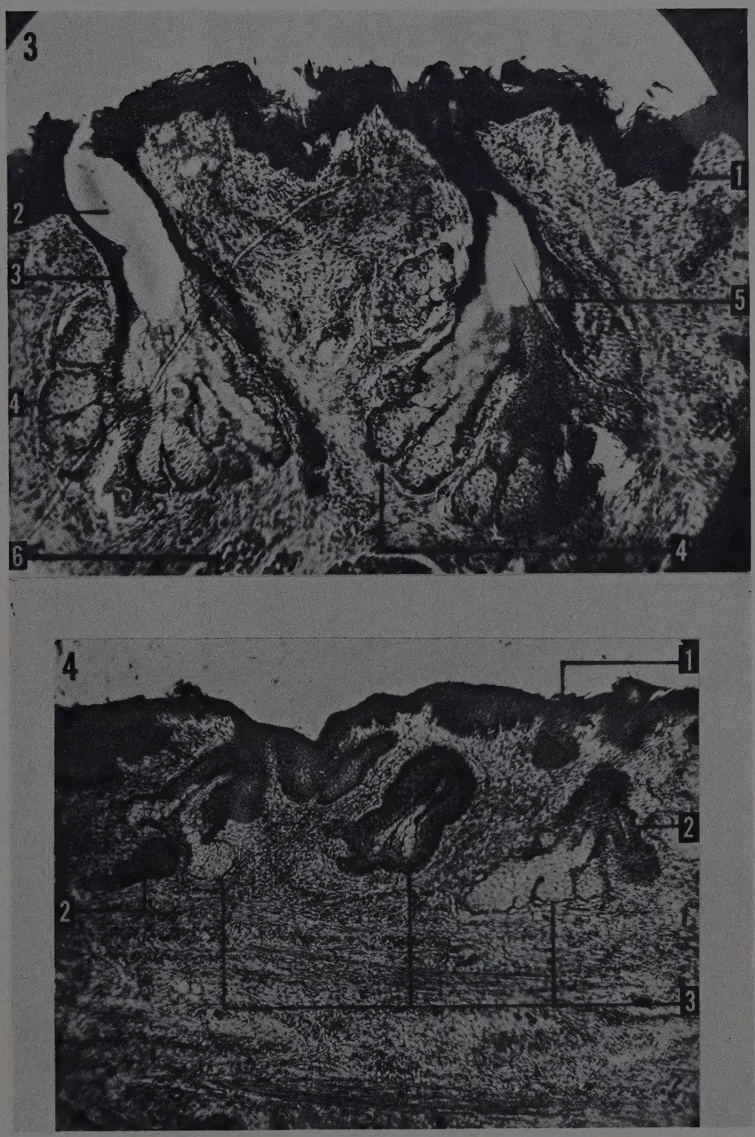
Arising either between the columns, from them or, as is more common, from the bottoms of the rectal sinuses, are found tubular ductlike structures extending into the subepithelial connective tissue and often called "anal crypts." These ducts or crypts very often give off secondary and tertiary tubular branches which end blindly in the submucosa or may penetrate into, or pierce through the muscularis of the anal canal. The central crypt (main duct) and its larger side branches seem to be the excretory passageways, whereas some of the tubules which branch off from the duct resemble the secretory units of the gland. We observed that most of the ducts had their outlets in the posterior side of the anal canal. The direction of the ducts and their terminal portions usually is caudolateral or caudal, rarely straight lateral (outwards) or cranial.

Each duct has one to six slender tubular end portions, some of which occasion-

EXPLANATION OF FIGURES IN PLATE II

FIGURE 3. Sebaceous glands of the circumanal area.
Sagittal section of the anal region. Newborn (♀). ×79.
1. Epithelium of the circumanal skin
2. Duct of the gland
3. Stratified squamous epithelium of the duct
4. Holocrine end portion
5. Hair follicle with the associated gland
6. Musc. sphincter ani externus

FIGURE 4. Sebaceous glands of the zona intermedia.
Sagittal section of the anal region. 22-yr old ♂. ×54
1. Stratified squamous epithelium of the zona intermedia
2. Rudimentary hair
3. Holocrine end portion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ally show knoblike protuberances which resemble alveoli. In some instances the end portions extend only as far as the z. columnaris lamina propria or submucosa, because the terminal tubules of some glands are short and seem to be undeveloped. A typical picture of so-called anal crypts or ducts with few tiny secretory end, portions is seen in figure 7. The caliber, the number of side branches and the diameter of the ducts, as seen in figure 7, varies considerably: in some places the lumen is only 7 μ in others 70 μ or more in diameter. The usual length of the main crypt (central duct) is 1.5 to 2 mm and only occasionally they reach 4 mm. Some of the terminal tubules reaching the submucosa at times become distended into small caeca. Others reach the submucosa of the z. intermedia, still others pierce the internal sphincter muscle and occasionally also the longitudinal muscle coat, or even reach as far cephalad as the ano-rectal line. Sometimes the glandular tubules inside the internal sphincter dilate into ampullalike structures which traverse the whole sphincter and penetrate the longitudinal muscle layer as seen in figure 8. From these enlargements branch off several small terminal tubules which penetrate still further laterally and end blindly in the connective tissue or, penetrating the longitudinal muscle coat, reach the area of the ischiorectal fossa. Scattered along the ducts and particularly about their terminal ramifications are found accumulations of lymphocytes. One of the intramuscular secretory portions of a z. columnaris gland seen in figure 8 is a rather large structure which can be seen macroscopically. It measures 0.91 x 1.28 x 2.1 mm. The distance from the opening in the anal canal to the apex of the ampulla is 6 mm.

The walls of the main ducts (crypts) are made up of stratified epithelium similar to that lining the z. columnaris from which the ducts arise, i.e., stratified squamous or stratified columnar type. The former, however, soon passes over into a stratified columnar epithelium which gradually becomes lower so that the secretory branches (terminal tubules, alveoli and ampullae) are lined by low cuboidal epithelium composed of two cell layers.

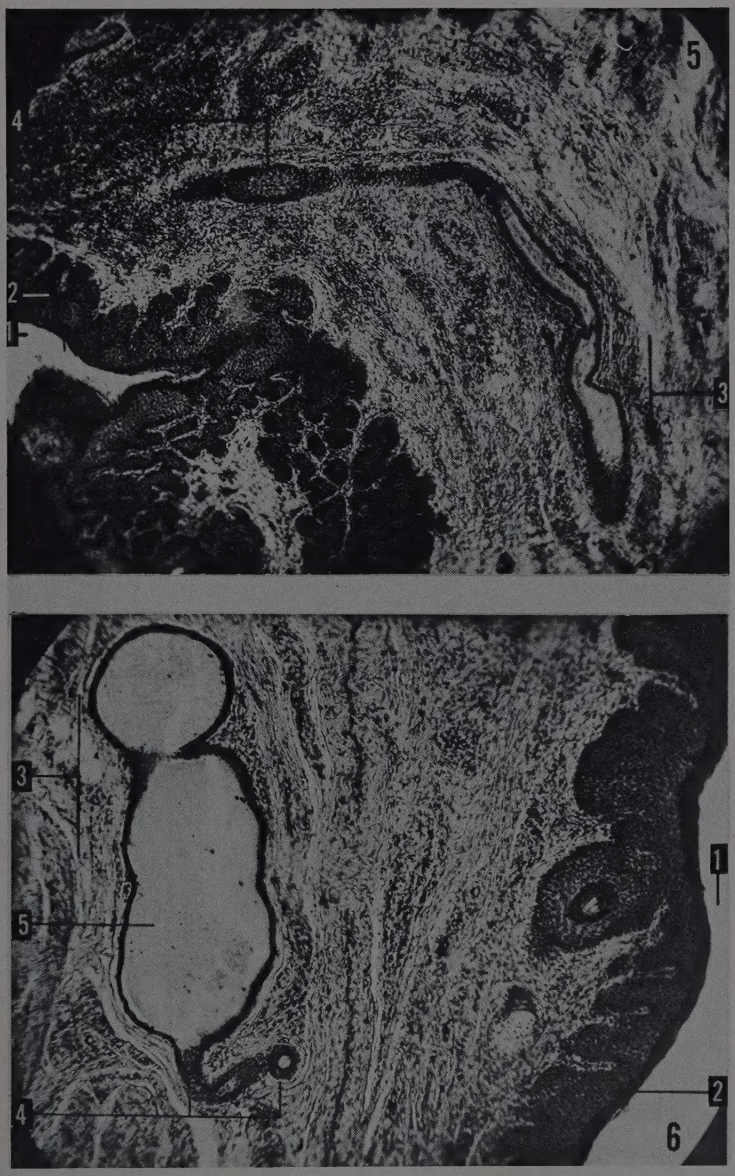
Epithelial channels which resemble glands were found in all our investigated z. columnaris regions. A wide individual variation, however, was noted in the number of glands, in their structural plan, mode of ramification, size, shape, location and in the depth to which they invaded the other tissues. Some individuals have many, well-developed and richly branched glands, others have only a few. For instance, the number of the specific, eccrine secreting z. columnaris glands present in a single individual varied from two to eleven; the average number of glands was three to five (a gland is considered being composed of one crypt with all the primary, secondary and terminal branches).

Considering the possible function of these above mentioned z. columnaris structures, it has to be emphasized that at least some of them are definitely glandular in nature, particularly those tubular or ampullar structures which are better developed and penetrate the muscularis. They are merocrine glands where the surface lining cells are eccrine secreting and in the lumina of which the secretion

EXPLANATION OF FIGURES IN PLATE III

FIGURE 5. Tubular apocrine glands of the zona cutanea.
Sagittal section of the anal region. 22-yr old ♂. ×54.
1. Lumen of the anal canal
2. Stratified squamous epithelium
3. Secretory portion of the apocrine gland; lumen filled with secretion
4. Excretory duct of the apocrine gland

FIGURE 6. Ampullalike apocrine gland of the zona cutanea
Sagittal section of the anal region. 22-yr old ♂. ×79.
1. Lumen of the anal canal
2. Stratified squamous epithelium
3. Secretory portion of the apocrine gland which suddenly passes into narrow excretory duct (4)
5. Lumen of the gland filled with secretion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is seen (fig. 8). Some of these lining cells give a positive reaction for mucus. The very few saccular outpouchings which show secretory characteristics, and those tubules the sprouts of which finally branch and resemble the end portions of a tubular gland should also be considered as secretory portions. In general; however, the epithelial channels of the z. columnaris should be considered as rudimentary structures which have lost most of their secretory portions and the secretory characteristics in their phylogenetic development. No sex difference was observed in relation to incidence or location of these structures.

The investigated material of the newborn shows, in general, the same distribution, branching and some ampullalike dilatations of these glandular structures as do the adult specimens. Some terminal portions are seen intramuscularly and a few cells show secretory characteristics. The length of the glands from the orifice till the terminal ends varies from 0.42 mm to 2.38 mm. It is our impression that in the newborn as in the adults these structures appear to be rudimentary.

DISCUSSION

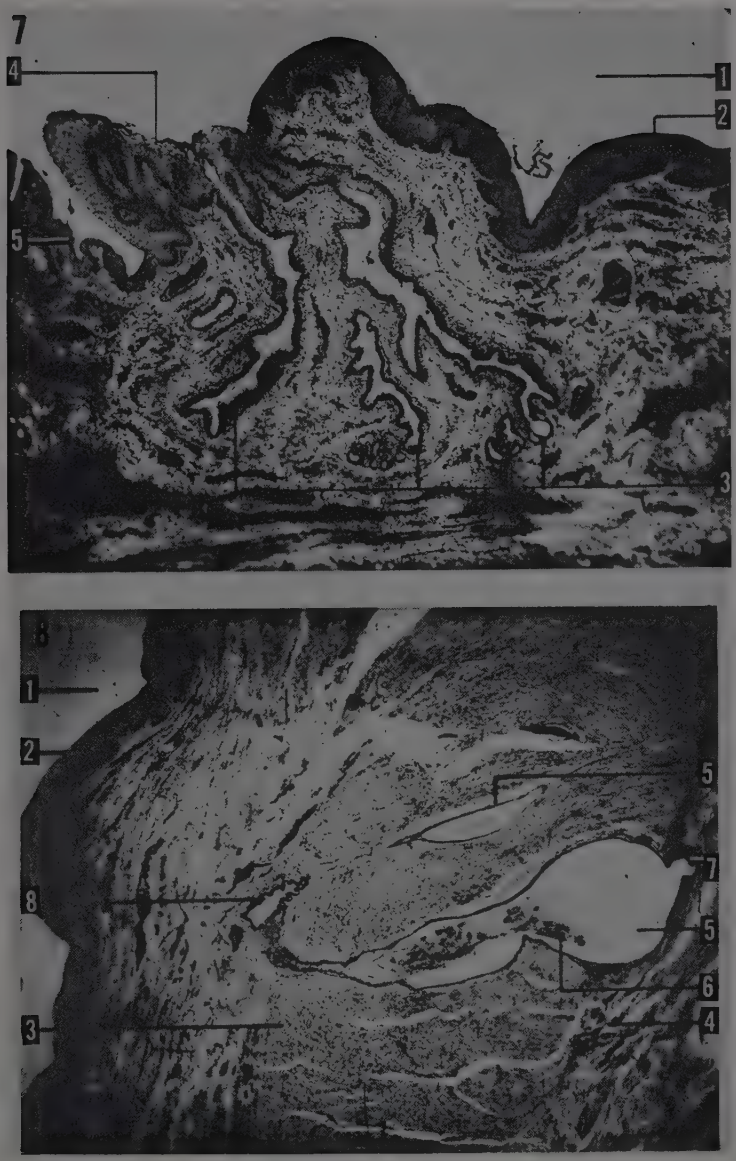
Sebaceous glands in the anal region have been seen by various authors who have investigated this area. They have been found circumanally, in the z. cutanea and the z. intermedia. However, there is some disagreement about the sebaceous glands of the z. intermedia. We cannot accept the findings of Robin and Cadiat (1874) that this zone is lacking entirely in hairs and glands. We also cannot agree with the observations of Koelliker (1850), Romiti (1899), Braun (1901) and Stieda (1902) that the sebaceous glands of this zone do not possess hairs. Our observations are in agreement with those of Szent-Györgyi (1913) and Hamperl (1925) who have reported two kinds of glands, with and without hair. Our findings, furthermore show that the majority of the z. intermedia sebaceous glands have rudimentary, undeveloped hairs which never reach the lumen of the canal. Accurate are the observations of Hamperl (1925) that "free" sebaceous glands in the z. intermedia are few in number. However, we are unable to confirm the report of Szent-Györgyi (1913) that "free" sebaceous glands reach full development only at the time of puberty. Our preparations show that the sebaceous glands of the adults are not much larger than those of the newborn.

Gay (1871) and Szent-Györgyi (1913) have observed sweat glands also in the z. cutanea of the anal canal but in our slides they are seen only circumanally. Moreover, Szent-Györgyi has reported the complete absence of sweat glands in the circumanal region of some individuals. Apparently the author may have had reference to the "large sweat glands," i.e., apocrine scent glands, because all humans possess eccrine glands in this particular area. Our observations con-

EXPLANATION OF FIGURES IN PLATE IV

FIGURE 7. Anal ducts (channels or crypts) of the zona columnaris.
Sagittal section of the anal region. 28-yr old ♂. ×30.
1. Lumen of the anal canal
2. Stratified squamous epithelium
3. Anal ducts
4. Rectal (anal) column
5. Transitional zone of the epithelium

FIGURE 8. Eccrine glands of the zona columnaris penetrating sphincter ani muscle.
Sagittal section of the anal region. 28-yr old ♂. ×24.
1. Lumen of the anal canal
2. Stratified squamous epithelium
3. Musc. sphincter ani int.
4. Stratum longitudinale recti
5. Ampulla of the eccrine gland
6. Secretion
7. Branch of the gland
8. Excretory portion of the gland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cerning the circumanal glands support the results of the investigations of Hamperl (1925), Petersen (1931), Sperling (1935), and Peter and Horn (1935) that in this area two types of tubular glands exist: eccrine and apocrine secreting. In addition we have demonstrated in the z. cutanea of some individuals modified, apocrine secreting glands whose secretory portions are not coiled (figs. 5 and 6).

There is much more confusion about the epithelial channels of the z. columnaris. Some authors (Morgagni, 1719; Haller, 1765; Herrmann, 1880; Johnson, 1914; Hamperl, 1925) believe that these tubes are glands; among others, however, Szent-Györgyi (1913) and Braun (1901) deny this. Our own observations on serially sectioned material from both the adult and the newborn lead us to confirm the view that these peculiar looking tubules and ampullae are glands.

We cannot accept the point of view of Szent-Györgyi (1913) that the z. columnaris ducts are nothing else than deeper sinus rectales "recesses of the mucosa." We also cannot approve the opinion of Herrmann (1880) and Herrmann and Desfosses (1880) that they are acinous glands, because in our preparations they are tubular. It is not feasible to designate these glands as "intramuscular glands" as does Johnson (1914) because the tubules do not always penetrate into the muscle tissue. More often they terminate in the submucosa of the anal canal. Hamperl (1925) wrote that he, as Morgagni (1719), had seen a large sacklike structure lined with epithelium in the z. columnaris but could not trace it because he had only one section of it.

We were also able to find such dilated secretory portions, and observe them in serial sections as shown in figure 8. Tucker and Hellwig (1933) and Tucker (1935) described the z. columnaris as being lined by transitional epithelium and Kratzer and Dockerty (1947) saw transitional epithelium in the proximal parts of the z. columnaris ducts. It is not advisable to call the stratified columnar or the stratified squamous epithelium of this zone transitional epithelium even though it lines a transitional zone.

Tucker and Hellwig (1933) and Tucker (1935) reported that the "anal ducts" originated from the z. intermedia. Our preparations show that they are z. columnaris derivatives. We do not agree with Johnson (1914) and Hamperl (1925) that the specific glands of the z. columnaris are entodermal derivatives. Johnson believed that the z. columnaris and the z. intermedia develop from entoderm and that the linea anocutanea is the demarcation line between ento- and ectoderm. Our opinion is that the anal ducts of the z. columnaris are of ectodermal origin and that there is no doubt that the z. intermedia is derived from ectoderm simply because it possesses sebaceous glands and hairs. The exact line of demarcation cannot be definitely located in our preparations of newborns and adults but it is somewhere in the neighborhood of the linea sinuosa analis as accepted by such authors as Herrmann (1880), Retterer (1890), Chwalla (1927), Pernkopf (1928), Politzer (1931), and Patzelt (1931, 1936). According to Berenberg-Gossler (1913, 1914), whose investigative results are based on teratologic findings, the whole anal canal is of ectodermal origin.

We are not in a position to discuss the development of the anal region glands because our material did not include embryos and because in the newborn the glands do not differ much from the adult glands. According to Johnson (1914), Patzelt (1931), and Hill (1949) and his associates the "anal" or "proctodeal" glands arise as epithelial buds and cords in the fourth month of gestation from the rectal sinuses, whereas the z. intermedia and z. cutanea glandular primordia appear in the twentieth week of intrauterine life.

Various names have been given to the specific merocrine, eccrine secreting glands of the z. columnaris. These are called: special acinous glands, secondary and tertiary Morgagni sinuses, glandular ducts, intramuscular glands, intramuscular sinuses, anal grooves, glandlike structures, anal glands, anal crypts, proctodeal glands and anal ducts.

In certain descriptions in the literature, there is confusion as to whether the

author is describing the duct or the secretory portion of the gland. Since these are vestigial structures, it is to be expected that the epithelium would be a typical secretory type only in scattered instances. As a result, delimiting duct from secretory unit may therefore be difficult and hence subject to personal interpretation.

A question arises as to what is the best name for these structures. Frequently they are called "anal glands", but this is confusing because there are different types of glands in the anal canal wall (see figs. 4–8). The name "anal glands" does not point out a specific type of gland nor does it indicate the exact location or the type of secretion. It simply designates all the glands which open into the anal canal. Also the name "z. columnaris glands" does not adequately characterize them, because occasionally in the most cranial part of this zone some Lieberkühn glands and goblet cells are found. A suitable name is "specific z. columnaris glands" but it seems to be too long. To avoid long designation and still retain the popular term "anal," we feel that the specific, merocrine, eccrine secreting glands of the z. columnaris could be called the "anal ducts." They are true glands; however, they appear as ducts because of their vestigial condition.

To compare and to get some concept of the possible biological function of the glands of the human anal region, we have also investigated this region in certain animals. Although the results will be discussed in a subsequent publication, we can state here that Leporidae (*Lepus cuniculus, L. varronis, L. europaeus*) and Myoxidae (*Eliomys quercinus*) possess glands some of which open in the most cranial part of the proctodeum and resemble the anal ducts of man. However, in these animals the glands are much better developed and appear very active. Some of the ducts and their terminal portions are located in or pierce through the muscularis of the alimentary canal as in man. The secretions of the different types of glands located in the anal region of animals cannot be designated as a lubricant of the anal canal; this could be a secondary task. The chief mission of these structures, however, seems to be the production of odoriferous substances which have meaning in the identification of the animal species, perhaps in its sexual life and in defense or offense. In behalf of the favorable location of the glands, when the sphincter muscle contracts, the secretion is discharged into the anal canal, at the anus or circumanally and covers the hairs and also anoints the feces.

In regard to the human scent-glands Schiefferdecker (1922) says that after man had assumed the vertical position and changed his form of life, the olfactory organ and the scent-glands of the skin gradually perished. However, even now, on certain occasions, the specific odor of the secretion of some skin glands serves as a sexual stimulus on some individuals. In regard to the skin glands of the anal region of man, there is no doubt that somewhere in the past they had important biological function, perhaps one as the lower mammals possess at the present time. However, now in the anal canal wall are seen only perishable glands, vestigial remnants such as the z. columnaris specific eccrine and the z. cutanea apocrine secreting glands. The histopathological importance of anal ducts has been assumed by certain pioneer investigators and recently once more emphasized by Tucker (1935), Kratzer and Dockerty (1947), and Hill et al. (1949). These structures have been considered as routes by which infection may be transmitted to the deeper tissues of the anal region, structures which may be responsible for cryptitis, periproctic and ischiorectal abscesses, cysts and tumors of this region. Therein lies their main interest, since this study has not attributed to them any useful function in man. In order to understand the possible importance of the anal ducts, and anal canal glands in general, as potential avenues for the spread of anorectal infection, one must realize the fact of their existence (see figs. 4–8). It is well known that the intestinal tract acts as a natural lodging for some pathogenic and nonpathogenic organisms which under certain stresses and strains may invade the adjacent tissues. Any irritation, trauma or alteration in bowel habit provides more favorable conditions for the spread of infections. Particularly

vulnerable are vestigial structures such as the vermiform appendix and the rudimentary anal canal glands.

It is obvious that after infection has started in a glandular duct it could continue to spread along all the branches of this gland. It was mentioned before that some terminal portions of the specific glands of the z. columnaris extend into the subepithelial connective tissue of the z. intermedia, others reach the rectal submucosa and still others extend outwards, penetrate the muscularis and occasionally reach the ischiorectal fossa. Moreover, in the z. cutanea are found modified apocrine secreting glands which only some individuals possess. All these locations of vestigial structures offer a logical explanation of abscesses and fistulas encountered occasionally in these areas. In observing the glands of figures 6 and 8 one can imagine the possibility of how easily the narrow duct of the gland may become obstructed and a cyst may develop.

It has always been difficult to explain the etiology of primary carcinoma when found in the perianal tissue. Scarborough (1941) has shown that the anal canal glands are not free from primary malignancy. He describes a primary carcinoma originating from "rudimentary remains of the anal glands." Such findings again have stimulated investigators to focus their attention to the glandular structures of the anal canal. Martin (1935) observed that in gonorrheal infection of women the anal canal also becomes infected in about half the cases. Tucker and Hellwig (1933) pointed out that in 22.1 percent of their material of infected anal ducts the infection was caused by the Neisser coccus. They emphasized that the anal ducts play an important part in gonorrheal reinfection by harboring the gonococcus.

In the descriptive part of this paper we have noticed that in man the number of anal ducts and also the other types of glands of the anal canal varies considerably from case to case. Some individuals have few, others many. It is believed that those persons with a relatively large number of glands have a greater predisposition to perianal complications than those with few glands.

SUMMARY

The glands of the anal region have been reinvestigated. Normal adult and newborn material was obtained shortly after death. The entire anorectal regions were examined in serial celloidin sections.

In the anal region there are four different types of glands: (1) holocrine secreting sebaceous glands, (2) merocrine, eccrine secreting sweat glands, (3) merocrine, apocrine secreting scent-glands, and (4) specific zona columnaris eccrine glands.

Sebaceous glands are found circumanally and in the z. cutanea and z. intermedia of the anal canal. In the z. intermedia three kinds of sebaceous glands occur: (1) with well developed hairs (2) with rudimentary hairs and (3) "free" or without hairs. Sweat glands are found only circumanally. Apocrine scent-glands are located circumanally and in the z. cutanea of the canal. Circumanal apocrine glands resemble those of the axillary region, whereas those of the z. cutanea are modified: some are simple tubules whose secretory portions are not coiled, in others the secretory portions are ampullalike sacks. In the z. columnaris, tubular structures arise from the crypts of the rectal sinuses. Some of the tubules branch in the submucosa, others penetrate the internal sphincter muscle or even reach the ischiorectal fossa. The intramuscular portions of these glands are usually distended in pear shaped sacks some of which measure 0.91 x 1.28 x 2.1 mm. These appear to be glands of the eccrine type.

All glands of the anal canal vary considerably among individuals in number, form and size. Although vestigial in man, these glands are yet clinically significant as pathologic sites.

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A NEW SPECIES OF *ACMAEODERA* FROM ARIZONA

COLEOPTERA: BUPRESTIDAE

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The following species of *Acmaeodera* is sufficiently distinct from described forms to warrant a name.

Acmaeodera hassayampae n. sp.

Male.—Form of *A. hulli* Knull (1928); dark, shining bronze on both surfaces; each elytron containing seven small yellow spots arranged in two lines, one line of four spots starting back of umbone, one at middle and two back of middle; other line near suture starting at middle and two back of middle.

Head with slight depression on front; surface densely, coarsely punctured, clothed with long white recumbent pubescence; antennae serrate starting with fifth segment.

Pronotum wider than long, wider at base than at apex, widest in front of middle; anterior margin sinuate, median lobe broad; basal margin truncate; sides broadly rounded; disk convex, transverse corrugated band at base, deep basal depression each side in front of band; surface in middle with coarse punctures, separated by their own diameters, denser and larger toward sides, long recumbent broadened white hairs in middle, appressed broader white scales toward sides.

Elytra near base wider than widest part of pronotum, widest back of middle; sides rounded at base, constricted back of umbone, widened back of middle, then broadly rounded to suture, margin serrulate on apical fifth; disk convex, umbone prominent, a narrow transverse basal depression; surface striately punctured, punctures separated by less than own diameters and diminishing in size toward apex, interspaces with line of minute punctures with a broadened hair arising from each, hairs slightly broader toward apex, broad branched appressed scales extending along sides from base four-fifths distance to apex.

Beneath clothed with broad appressed branched scales, meso- and metasternal epimera clothed with long recumbent white hairs, posterior margins of third and fourth ventral segments with long recumbent hairs. Anterior margin of prosternum retracted from side margin, with a stout rounded tooth on each side of middle.

Length 6.4 mm; width 2.1 mm.

Female.—Slightly larger than male, last three ventral abdominal segments densely, minutely punctate, a long recurved hair arising from each puncture.

Holotype ♂, allotype, and paratypes collected at Wickenburg, Arizona, June 16, 1937; also June 29, 1939, by D. J. and J. N. Knull; in my collection. Paratypes in collection of The Ohio State University.

Variations.—Yellow spots of elytra are variable in size and placement. Sometimes an extra spot along suture near base is present, or spots may be united. Length varies from 4.8 to 7.7 mm.

This species is close to *A. varipilis* Van D. (1934), which is more elongate, has wider, more coarsely sculptured pronotum. From *A. hualpaiana* Knull (1952) it differs by having posternal margin with a well developed tooth each side. *A. hualpaiana* has a median truncate lobe. From *A. hulli* Knull it differs by having two rows of yellow markings on each elytron instead of one row, is less shining and spatulate scales toward apices of elytra are narrower.

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INSTRUMENTATION IN THE UNDERGRADUATE CHEMISTRY CURRICULUM*

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The word "instrumentation" is defined in Webster's New Intercollegiate Dictionary as, "a use of, or operation with, instruments." The dictionary includes several definitions of the word "instrument," but the one which is applicable to the present discussion is, "a measuring device for measuring the present value of the quantity under observation." Thus in considering instrumentation in the undergraduate chemistry curriculum we are concerned with the use of measuring devices.

RELATIONSHIP OF INSTRUMENTATION TO CHEMISTRY

Chemistry may be defined as the study of the composition, structure and properties of matter and the changes which it undergoes. Measurement is absolutely basic to all of chemistry for it is impossible to gain knowledge of matter without some means of measuring its composition, structure, and properties, and to recognize changes therein.

Measurement has been basic to the historical development of the knowledge which makes up the subject matter of chemistry. In fact, the rate of the development of this knowledge in each period of history bears a direct relationship to the variety, number, and precision of the tools of measurement which were available and which were employed in that period. The tremendous strides in developing and establishing chemical knowledge in the seventeenth century are directly attributable in large part to the availability and the use of the analytical balance, which is even today one of the most important instruments in chemical work. The greatly accelerated rate of chemical development in the current generation is due to a considerable extent to the variety, number, and accuracy of the tools of measurement which are now available and which are constantly being expanded and improved.

Measurement is basic, not only in the historical development of chemical knowledge, but also in virtually all areas of current research in chemistry. The idealized goal of research is the gaining of new knowledge, the refinement of current knowledge, or both. All scientific knowledge, with the possible exception of that on the most primitive levels, must be quantitative or, at least, semi-quantitative. And the gaining of quantitative knowledge is impossible without the tools whereby quantitative measurements can be made.

Measurement is, in addition, fundamental and basic in the practice and in the practical application of the knowledge which makes up the subject matter of chemistry. The tools of measurement are absolutely necessary in industry and in the home and wherever chemistry is practiced and chemical knowledge is applied. Therefore, instrumentation is intimately related to all of chemistry, in its historical development, in current research toward the expansion of chemical knowledge and in the application of that knowledge as well.

In viewing the very close relationship of instrumentation to chemistry, it is of utmost importance to maintain the proper perspective. Within chemistry, the instruments are the tools for achieving an end and are not the end in themselves. The instruments are merely the tools for use in the study of the composition, structure, and properties of matter and the changes which it undergoes.

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The role of instrumentation is easily subject to overemphasis on the one hand and to underemphasis on the other hand. Instruments are overemphasized in chemistry if they are considered to be the end in themselves. For example, the analytical balance, the spectrophotometer and x-ray diffraction instruments are not end-goals in chemistry, rather it is the knowledge to which measurements by means of these instruments can contribute that is chemistry. Instruments are underemphasized if chemical knowledge is studied without consideration of the tools whereby that knowledge has been gained. There is doubtless a proper place in scientific work for those specialist individuals who work solely in the theoretical realm with no consideration of the means whereby theory may be verified, refined, and applied. However, a general study of chemistry must include a study of the tools of measurement.

PLACEMENT OF INSTRUMENTATION IN THE UNDERGRADUATE CURRICULUM

In considering where instrumentation belongs in the undergraduate curriculum, it is well to base the consideration upon the core curriculum as adopted by the appropriate agency of the American Chemical Society. This does not mean that departures, even radical ones, from this recommended curriculum may not be in order either now or in the future, but it does represent a well-established basis for considering any particular part of the curriculum. The recommended program may be summarized briefly as follows:

1 year of general-inorganic chemistry
1 year of analytical chemistry
1 year of organic chemistry
1 year of physical chemistry
advanced chemistry course(s) of 5 semester hours credit
mathematics through calculus
1 year of physics
foreign language
social sciences, humanities, etc.

There are, in principle, three distinct means whereby instrumentation can be placed within this curriculum. First, instrumentation can be considered here and there throughout all of the courses in chemistry and physics. This is to say that, as the knowledge within the various areas of chemistry is studied, the tools of measurement whereby that knowledge has been developed and established can be studied simultaneously. This is done, of course, to a considerable extent in all of the science parts of the undergraduate curriculum. However this approach is hardly an adequate one insofar as instrumentation is concerned. The progress in this and recent generations in the development of unifying concepts has been so great that these concepts can be presented to good advantage early in the study of chemistry, even at times when the students are hardly ready to understand and to appreciate the means whereby those concepts have been developed.

The second means whereby instrumentation can be located within the undergraduate curriculum is to concentrate it in those courses which are particularly quantitative, that is, in physical chemistry and in quantitative analysis. Some attention is given to the tools of measurement in virtually all undergraduate courses in physical chemistry. However, the theoretical essence of the subject of physical chemistry precludes laying too much stress on the tools involved. Furthermore, the current trend in instruction in physical chemistry, particularly on the more advanced levels, is toward a more rigorously mathematical basis rather than to a more experimental basis. The place of instrumentation in the quantitative analysis course will be considered in a later section in some detail.

The third means whereby instrumentation can be located within the undergraduate curriculum is by introduction of a separate course in instrumentation, either as all or part of the recommended "advanced chemistry course" or as an

additional feature of the curriculum. This subject will also be considered in more detail in a subsequent section.

INSTRUMENTATION IN QUANTITATIVE ANALYSIS

The course in quantitative analysis is in a sense devoted to the methods of quantitative measurement of chemical composition and the practical and theoretical concepts underlying that which is measured. A quantitative determination generally includes a separation and a measurement. On the basis of the type of measurement, quantitative procedures are typically classified as gravimetric, volumetric, electrical and optical, often with a miscellaneous category added as well. In a one-semester course in quantitative analysis, it is customary to emphasize gravimetric and volumetric methods with relatively little consideration of electrical and optical methods. Therefore it is only proper to consider in some detail in this first course instrumentation as it applies to gravimetric and volumetric methods, particularly the analytical balance.

The second semester course in quantitative analysis does, in some institutions, continue the emphasis upon gravimetric and volumetric methods, perhaps with special consideration of more complex separations than are usually encountered in the first semester course. Even though much can be said in favor of a full year devoted primarily to gravimetric and volumetric methods, it seems that it should be entirely proper to give primary emphasis to electrical and optical methods in the second semester course in quantitative analysis. The designation of this course as one in "instrumental analysis" is somewhat of a misnomer, although this terminology is fairly well established already. Constant care is required lest the optical and electrical methods be considered as a subject apart from "classical" quantitative analysis, and the optical and electrical methods should, in fact, build upon the gravimetric and volumetric methods first encountered.

Many schools already offer a course of this type. It is usually placed in the curriculum after at least one semester of the course in physical chemistry. There seems to be no a priori reason, however, why this type of course could not directly follow the first semester of quantitative analysis. The earlier placement of the course would necessitate a less rigorous treatment of such topics as conductance of electrolyte solutions, but this should not be a prohibitive disadvantage.

If this course is designated as one of the two semesters of regular analytical chemistry, it must be taken by all full chemistry majors. If, however, the year of analytical work is filled by a separate course in qualitative analysis along with the first course in quantitative analysis, then the second course in quantitative work must be considered as part or all of the "advanced chemistry" recommendation in the American Chemical Society curriculum and must compete with several other courses in faculty planning and in student selecting. This topic will be discussed further in a later paragraph.

The subject matter of the course in optical and electrical methods becomes fairly well established, even though variation does properly exist from one institution to another. The optical methods include (1) those based upon the emission of radiant energy, as in arc, spark, and flame emission spectroscopy, (2) absorption methods as in colorimetry and spectrophotometry, (3) light scattering methods as in turbidimetry, nephelometry, fluorimetry, and phosphorimetry. All regions of the electromagnetic spectrum from radiowaves and microwaves to x-rays and gamma rays should be considered. Also, ion-optical methods such as mass spectrometry should be included. The electrical methods should include those based upon measurement of all common electrical quantities, such as potentiometric, conductometric, amperometric, polarographic, and coulometric methods. Along with the optical and electrical methods, it is well to include consideration of a number of miscellaneous methods such as chromatography (especially vapor

phase), thermal conductivity, radiochemical methods of analysis, and perhaps some others.

A wealth of literature is available in easily accessible forms for use in a course of this type. A half dozen regular textbooks are currently on the market. The annual review articles in the April issues of *Analytical Chemistry* provide excellent summaries of current work in each of numerous areas related to instrumentation as well as extensive listings of references. Regular feature sections on instrumentation have been included for several years in *Analytical Chemistry* and in *Industrial and Engineering Chemistry*. A new feature section has recently been established in the *Journal of Chemical Education* which provides excellent coverage of various areas of instrumentation which, perhaps, should be classed as required reading for all teachers and students of chemistry. In addition, the commercial development and manufacture of chemical instruments has become a very active field with the result that the several manufacturers provide excellent instructional information in their advertisements and in other literature which they freely provide.

The expense of equipment is often cited as a deterrent to the establishment of laboratory courses in optical and electrical methods of analysis. Much analytical equipment is expensive, to be sure, but it is possible to provide a reasonably adequate laboratory course in this subject within a budget entirely consistent with other instructional expenses. Relatively simple and inexpensive spectrophotometers for use in the visible region are available from some manufacturers, and the principles involved can be taught almost as well with instruments employing visible light as with ultraviolet light. Infrared spectrometers are still quite expensive for undergraduate teaching purposes, although less expensive instruments have recently come on the market. The simpler spectrophotometers can be used directly for turbidimetric measurements and, with some modification, for fluorescent and other types of work. A pH meter can be used for a variety of electrometric measurements, and need not be limited to simple potential measurements. Also, an inexpensive vacuum tube voltmeter which may be purchased in kit form for 26 dollars is very satisfactory for student use with several electrode systems and in numerous applications A constant current supply for coulometry need consist of nothing more than a few batteries and a resistor. Homemade apparatus for gas chromatography can be very satisfactory, although a recorder such as the relatively inexpensive Varian models is very useful for this and some other types of work as well. Some of the equipment can be used for other courses and for research by students and staff, thus easing the financial burden attributable to this course. Furthermore, of course, it is not necessary to provide laboratory experience in every type of analysis discussed in the classroom.

Another possibility whereby the instruction can be carried out with a minimum of expense for laboratory equipment is to obtain actual data from other laboratories from which the students can make all necessary calculations and interpretations. For example, x-ray diffraction patterns, infrared spectra, and mass spectra form three types of data in which most of the instructional value lies in the treatment of the data, not in the running of the instruments. One company is currently planning to provide at low cost actual copies of sets of data of this type for instructional use.

Professors who have had experience with a course of this type almost invariably become enthusiastic about it. It provides much opportunity to teach chemistry, the initial fears of some persons notwithstanding. The quantitative approach to chemistry is extended beyond that of prior courses in the chemistry curriculum. Of considerable importance is the enthusiasm which the course generates among the students. Some students are "sold" on particular types of chemical work as a result of the course. All students, whether interested primarily in one area of chemistry or another, are able to recognize readily its importance to them.

SEPARATE COURSE IN INSTRUMENTATION

Two objections immediately arise when the possibility of a separate course in chemical instrumentation is suggested. The first is the feeling that chemistry courses should be courses in the subject matter of chemistry and not in the tools of measurement whereby that subject matter has been established and is applied. This viewpoint is generally valid, but it may be noted that the curriculum already does include "tool courses," such as those in mathematics and, in some respects, those in foreign language. Furthermore there is occasional precedence for a tool course within the chemistry curriculum as, for example, chemical microscopy. A second objection is the feeling that instrumentation is not strictly chemistry, so that if a special course is needed it should be provided in some other department just as the desired mathematics courses are provided by a separate department rather than within the chemistry department. This viewpoint is a reasonable one, but the fact is that such courses are generally not available in any other department. So if the chemistry faculty really feels the need of a separate course in instrumentation, it is almost forced to provide it. It may also be noted that the approach of physicists and engineers, for example, to instrumentation is not entirely the same as that of chemists, although there is no basic reason why this must be so.

Let us now consider from a positive standpoint the need for a separate course in chemical instrumentation. On a purely empirical and practical basis, much can be said in favor of such a course, simply because much of importance is left out of the regular courses in the curriculum. A chemistry student can successfully complete the usual undergraduate curriculum and have little or no familiarity with such topics as electronics, vacuum gauges, thermoregulators, self-balancing potentiometers, indicating meters, optic design in instrumentation, and even such terminology as "input impedance" and "transconductance." This deficiency points to a possible need for a separate course in instrumentation.

On a more fundamental basis, there are basic principles widely applicable in virtually all measuring operations. Unless these basic principles are considered and used, the whole subject of measurement and instrumentation is nothing more than a hodge-podge of largely unrelated items. It is hardly appropriate to take the necessary time in one of the regular courses in the basic areas of chemistry to consider the underlying principles of instrumentation, so the possible need for a separate course is indicated.

It may be claimed with considerable justification that there is a science of instrumentation. The time may come when separate departments or divisions of instrumentation will be established, with full professional majors therein. It is interesting to note the present existence on a high scientific level of societies and journals which specialize in instrumentation.

If a separate course is to be provided in chemical instrumentation, where does it fit into the curriculum? Inasmuch as instruments are tools of measurement, the course perhaps could come early in the curriculum. However, the student generally gains little appreciation of a tool until he has some concept of what it is for. Therefore it appears that the best place for the course in instrumentation is on the advanced course level, perhaps as all or part of the five hours recommended for advanced chemistry courses in addition to the four regular year-courses. This placement permits a proper building upon the material of the other chemistry courses, particularly with respect to the possible transducers encountered therein.

The instrumentation course must compete in faculty planning or in selection by the students with other advanced chemistry courses, or in both of these. The same place in the curriculum is often filled by such courses as organic qualitative analysis, advanced inorganic chemistry, a third semester of physical chemistry, biochemistry, senior research, and even by a course in "instrumental analysis" if the latter is not counted toward the two semesters of basic analytical chemistry. Every one of these courses is of considerable value. Yet it would be decidedly

unrealistic to claim that any one of them is absolutely the best one for all undergraduate students of chemistry. It does seem, however, that the case for a separate course in chemical instrumentation is sufficiently strong to warrant consideration along with the other possibilities when faculties plan which advanced course or courses are to be offered and when students and their advisers select which of the available courses shall be taken. All of these courses, including the one in chemical instrumentation, may be on what is commonly designated as the "advanced undergraduate-graduate" level. Those students who do go to graduate school generally get some of these courses in their graduate work. Some who do not continue into graduate school may profit more from one of these courses than another, but one in chemical instrumentation surely warrants some consideration. In no case is it feasible for a student to take every course from which he can receive some benefit. The responsibility to learn and to achieve must ultimately rest upon the individual, and no curriculum can in any sense provide a complete mechanism for the fulfillment of that responsibility.

The specific development of separate courses in chemical instrumentation has not yet proceeded very far. Circumstances would doubtless cause variation in the course outline from one situation to another. Among the main topics to be considered, however, would likely be transducers, electronics, servo-mechanisms, indicating meters, recorders and controllers, and perhaps some optics and pneumatics. A transducer may be defined as any device which will convert phenomena under investigation to an appropriate signal. Over 500 different types of analog transducers are now available, but there are relatively few types of output signal. The output signal is often electrical, consisting of a voltage, a current flow, a resistance, a capacitance, an inductance, although it need not be electrical. There possibly are millions of electronic circuits available in practice and in possibility, yet much is quite standard insofar as the fundamental operations are concerned. The course in instrumentation should include consideration of the major components of electronic devices and of the principle types of circuits encountered. A servomechanism may be considered to be a null or balancing device, whereby the effect to be measured is opposed by an equal and opposite effect automatically and continuously. In theory and in practice, a study of servomechanisms provides a unified and general method of attacking most classes of measurement. It should be noted that current trends in instrumentation go beyond the mere improvement of classical techniques of chemical measurement, and this fact accentuates the need for a separate course in the principles of instrumentation.

SUMMARY

Instruments are the tools of measurement whereby the knowledge which makes up the subject matter of chemistry is obtained and established and whereby chemical knowledge is applied. Therefore, instrumentation is intimately related to all of chemistry and must occupy a prominent position within the undergraduate curriculum. Instrumentation can be included in all of the courses in chemistry as an adjunct to the study of each part of the subject matter of chemistry, particularly in those courses which are predominately quantitative such as physical chemistry and quantitative analysis. The second semester in quantitative analysis can properly consist primarily of optical and electrical methods of analysis. In addition, however, it should be noted that there are basic principles which are widely applicable in virtually all measuring operations, and these principles can be treated adequately only in a separate course devoted to chemical instrumentation

THE BEGINNING COURSE IN QUANTITATIVE ANALYSIS*

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The great importance of chemical analysis is widely recognized in industry. Whenever variation in composition affects the properties of materials, they are bought, made, used, and sold on the basis of tests and analyses. Likewise heavily dependent upon analysis are clinical diagnosis, enforcement of various laws, most chemical research, and many other activities.

From the days of Berzelius and Liebig, analytical chemistry has had a prominent place in the education of chemists. Continued recognition of this status is shown by the requirement of two semesters of work in the subject by the committee of the American Chemical Society which accredits colleges offering a major in chemistry. Probably every college of significance has at least one course in analytical chemistry.

If the subject is so well established, why should one reconsider the beginning course? Perhaps the most important reason is the ever-increasing number of new techniques and methods being published. Examination of current issues of *Chemical Abstracts* will reveal an amazing number of publications on new instruments and methods of analysis, and on improvements of old methods and instruments or adaptation of them to new situations. Many annual or biennial review papers summarize the progress in specific areas.

As a background for all of these advances we have a wealth of analytical information accumulated during the past two centuries. To introduce the student to the essence of all of this, the old and the new, what should be done and how may one do it? Judging by the many textbooks published, there are many different answers. Apparently all possibilities have not yet been exhausted, for new books continue to appear.

The present discussion is limited to quantitative analysis. However, the indispensability of qualitative analysis in a vast number of situations must not be forgotten. Experienced quantitative analysts know that in most situations it is very hazardous to try to apply a quantitative method to a material whose qualitative composition is unknown. The presence of unsuspected constituents many cause very erroneous quantitative data.

In considering the beginning course in quantitative analysis I presume to state again only my own views. Although they have been recorded, both in papers and books, it is frequently worthwhile to reconsider one's position. That others have different views is evident from many publications on the subject.

The definition of chemical analysis used is that attributed to Robert Boyle; namely, the determination of the composition of substances. It should be noted that this definition implies no limitation on the kind of techniques which may be employed.

OBJECTIVES

Before deciding upon the content of a course, and on the method of administering it, one should be reasonably clear on the objective(s) of a course. Quantitative chemical analysis is no exception.

I believe that the over-all objective is to introduce the student to the body of knowledge generally considered to constitute quantitative analysis. More specifically, this means to sample the subject by selecting representative methods

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which will give a balanced perspective of the most important problems of analysis and of some of the methods of meeting them.

Probably few teachers actually try to train analysts as such, that is, to do particular determinations expertly. Only practice (correctly done) makes perfect, and this takes too much time for each new assignment. Rather, the objective is to impart a feeling for analysis, the basis of methods, how they are applied, the kind of data they yield, and something of the problem of obtaining reliable results. Not unimportant are the following psychological and educational by-products suggested many years ago by W. S. Frost: (1) stimulation of logical mental processes; (2) training of the memory; (3) practice in learning to work effectively; (4) cultivation of self-reliance and resourcefulness; (5) development of neatness and care; (6) education in dependability and integrity; (7) encouragement in the use of the scientific method; and (8) development of respect for natural laws.

BASIC OUTLINE

In theory at least, quantitative analysis encompasses the possible determination of all of the chemical elements, the many radicals and ions, and the almost numberless compounds. The last category alone comprises more than 600,000 organic compounds. At least one, and usually several, of these entities will be found in every separate natural and synthetic substance known. Thus, it should be evident that the analytical problems faced by the chemist are substantially limitless in dealing with all possible kinds of combinations.

Into what broad outline can one fit the basic operations and processes available to the analyst for determining desired constituents, in any possible relative amounts, in any and all kinds of substances, whether inorganic or organic? More than two decades ago I suggested considering the problem in terms of the unit operations and processes involved. The following brief outline is my best answer thus far.

I. *The sample.*—It seems obvious that analyses cannot be made without samples. The topics enumerated are most likely to be of concern in practical analysis.

1. *Selection and preparation.*—Homogeneous materials present no problem, provided enough is available for the required determination(s). In contrast, obtaining a representative sample from some heterogeneous materials is one of the most difficult analytical operations. In spite of this fact, a recent survey of 50 books revealed that 20% of them did not mention sampling.

2. *Measurement.*—Usually the amount of a desired constituent is reported in terms of the amount of the sample used. Percentage is the most common basis, although others are employed. Sometimes, as in densimetry, measurement is not employed, but it was necessary in establishing some kind of scale or calibration curve. The two most used methods of measurement follow.

a. *By mass.*—The operation of determining mass by weighing is known to every chemist. The equal-arm (analytical) balance is the analyst's best known instrument, a fact some instrumentalists forget. Solids, liquids, and gases may be weighed, although gases usually are not.

b. *By volume.*—Volumetric measurement is often used for liquids, and widely employed for gases. Unless otherwise specified, the liter, rather than the cubic meter, is the unit.

c. *Other methods.*—Occasionally some other method is used, such as manometry for gases.

3. *Preliminary treatment.*—Many kinds of samples require one or more preparative processes prior to measurement of desired constituents, even though no separation is necessary. The following types are most common: fusion; dissolution; and adjustment of conditions, such as acidity, oxidation state, and complexation.

II. *The desired constituent(s).*—A quantitative analysis always involves the determination of one or more desired constituents. Unless there is some interference, one proceeds directly to such determination(s) on the sample after appropriate preliminary treatment(s) (if necessary).

1. *Separation.*—In case of interferences (known from qualitative analysis), separation is necessary unless provision can be made to correct for or avoid them. The following separative processes are widely employed: volatilization, precipitation, electrodeposition, dissolution, absorption, adsorption, ion exchange, and liquid-liquid extraction. There are others, of course.

It should be emphasized that such separations are always avoided, if possible. Except for any necessary preliminary treatment(s), here one finds practically all of the chemistry involved in a method of analysis. The objective, of course, is to isolate some system the purity of which is known with a certainty adequate to enable one to measure the desired constituent(s) with the required accuracy, or which is free of possible interfering constituents.

The necessary preparative chemical steps may be long, tedious, and exacting. Not frequently much experience and skill are needed to accomplish them. Sloppy manipulation and disregard of operative details may lead to serious errors. No separation process has any inherent connection with any particular kind of measurement.

2. *Measurement.*—In the determination of any desired constituent, by any kind of method, measurement is the final and inevitable analytical operation. Measurement consists, of course, in determining the number of times the standard goes into the unknown. The entity measured is always some property. It may be a specific property of the desired constituent, or of something bearing a known relationship to this constituent. Thus, to determine silver one may measure the mass of electrodeposited metal or of precipitated silver chloride. Or it may be a systemic property such as the density of a solution of sulfuric acid, from which the amount of desired constituent can be ascertained. No matter what the property, or the means employed to measure it, the operation is physics.

The number of properties measurable for analytical purposes is fairly large. The number of ways of measuring them is much larger. Altogether, the possibilities are bewildering to anyone except a widely experienced analyst. Thus, 72 kinds of spectrophotometers have been suggested. The field has developed until a monograph of hundreds of pages is required for each of a number of these techniques, examples being emission spectrometry, polarography, and titrimetry.

SELECTION OF MATERIAL

It is hoped that enough has been stated to indicate the enormous range of information available which deals with quantitative chemical analysis. It comprises (1) all of the chemistry—inorganic, organic, and physical—which is used to prepare systems for measurement, and (2) all of the physics basic to the instruments used to make the measurements. All measurement is instrumental.

What should the instructor select from all of this for a beginning course? Several items need to be considered.

Nature of course.—An important point is the kind of course. If it is for one semester, less material can be included than in one covering two semesters.

To enhance motivation, the student's interests may be considered. Thus, a one-semester course for students in home economics may well be slanted differently from one for students in chemical engineering. However, the principle of weighing a sample is the same in the two cases; but the girls feel better if their samples are baking powder, and the boys if theirs are soda ash.

Emphasis sought.—The course should be analytically realistic. That is, in the limited time available, it is probably a waste of time in most instances to dwell on abstruse theories of chemistry or physics. Also it is probably of questionable

value merely to press the switches and read the meters of a large number of instruments.

What seems much more desirable is a broad understanding of the problems and methods of analysis This involves (1) the chemistry necessary, if there is any, to render the desired constituent measurable; and (2) the properties measurable, together with the means available and their limitations.

In addition, it has been my experience that the design of a workable method for a specified, new situation is a very enlightening exercise. Primarily it must be based upon information from the library. If feasible, it should be tried in the laboratory. This is a very simple introduction to research.

Personal choices.—Somewhat arbitrarily I devote the first semester to titrimetry and photometry, with some attention to the sample, particularly its selection, measurement, and preliminary treatment. Then in the second semester I cover gravimetry and polycomponent analysis, including the design of a method for a four-component hypothetical alloy.

Thus, this includes three very widely used methods of measurement. Using polycomponent samples in the second semester, such as limestone, bronzes, and alloy steels, provides a very practical situation for discussing the chemistry and techniques of a variety of separatory processes. Also, as time permits, the principles and applicability to these materials of other methods of measurement are discussed. A good example is the possibility of using emission spectrometry and electrometry for such materials

THEORY

Although one is accused occasionally of training determinators, rather than analytical scientists, it is doubtful if any instructor seriously attempts to achieve the former objective. Industrial laboratories do not train routine analytical operators as students are handled in college classrooms.

My advocacy of a broadly based viewpoint in teaching quantitative analysis comtemplates the inclusion of some theory, both with respect to the chemistry and the physics involved. Generally the more basic the knowledge one has on a subject, the better.

The common meaning of theory is an interpretation or explanation of a phenomenon. That is, it concerns the how and why of things. For example, sodium chloride crystals are white and cubic; silver chloride is curdy, barium sulfate is crystalline, and hydrous ferric oxide is gelatinous; silver chloride adsorbs very little and barium sulfate strongly; and ferric ion forms with chloride ion yellowish $FeCl_4^-$ and with fluoride ion colorless FeF_6^{3-} ions. Why are the stated facts true and how do the processes involved operate? Relevant theories are attempts to interpret such facts, as science consists of facts and their interpretations. Interpretation is the role of physical chemistry.

What should and can be done here is the most serious question in teaching quantitative analysis. Probably no two teachers would agree.

Firstly, what can be done? The great majority of students reach the course today as sophomores. Consequently, they are probably just taking calculus, and may be in their first course in physics. Most of them know little or no organic chemistry, and they have not taken physical chemistry.

Secondly, what is worth doing? Should the instructor attempt to go into the mathematical theory of sampling heterogeneous materials? When the sample is to be weighed, should he consider the theories of gravitation, of the engineering design of the balance, and of the corrosion of the weights? Assuming that the sample is a silicate and that the iron is to be determined absorptimetrically as the 2,2'-bipyridine complex, should one take up the theories of the fusion process, the precipitation separation of the iron as the hydrous oxide, the reduction by hydroxylamine, the indicator action in adjusting the pH, and the complexation with the

2,2'-bipyridine? Then follows the measurement. Referring only to the detectors in absorptimeters, what theory is to be included for visual, photographic, and photoelectric detection?

I do not know the answers to these and many similar questions. Inasmuch as capable graduates come with a great variety of backgrounds, evidently no one viewpoint is critical in teaching. No doubt we should do what is feasible in the situation, but without forgetting that quantitative analysis is essentially a practical subject. Someone stated that quantitative analysis is half an art and half a science. Any relevant theory relates to the chemistry and physics involved in specific applications.

LABORATORY WORK

A course without laboratory work is comparable to a lecture or recitation course, or both, on driving an automobile without actually driving one. I have suggested certain objectives for a broadly based course. Part of these, especially the skill in, and understanding of, the art, can probably be achieved only in the laboratory. The science involved is a subject for the classroom.

What is selected is not critical as long as one achieves his basic objectives. The principles of weighing and handling a stable sample have nothing to do with the composition of the sample; as industrial materials, nonferrous alloys, alloy steels, and limestone do not go out of style because of current interest in plastics and uranium. In any case, the samples should serve as means for illustrating principles of chemical preparation and/or separation and of measurement, rather than as analytical ends in themselves.

Today it seems impossible to introduce students in any significant way to all of the apparatus and instruments available for separation and measurement. Anyway, I know of no evidence that industry wants the product of a button-pushing, meter-reading excursion past an array of expensive instruments.

Neatness, care, reliability, and an understanding of the basic problems of separation and measurement are desirable. Equipped with these, along with general intellectual capacity, a will to work, and ability to work with others, the student need not fear for his analytical future.

Unless measurement alone is the objective of a course, the samples should be realistic. The industrial analyst's first concern is always with materials. Thus, the titration of a solution of ferrous ion with permanganate illustrates nothing of the separative and preparative chemistry necessary if iron is to be determined in many kinds of materials. Practically, one seldom finds iron ready to be titrated. For large classes I believe in using a large series of analyzed samples, although for statistical evaluation, all students should use the same sample material for any given assignment

Finally, the laboratory notebook should be mentioned. The instructor can do much here to cultivate sound habits of handling laboratory data. The particular form of book is not important, but the entries should be in a consistent form.

Specific entries should be adequate to enable one skilled in the art, i.e., one trained in analytical chemistry, to know the kind of sample, the method employed, and the supporting data for the results reported.

In addition, the record should be dated and signed by the determinator. These two items are musts if the record is to be submitted in legal cases, such as suits involving patents or law enforcement. Also in chemical companies often someone wants to know who did certain analyses long after the work was done.

NUMERICAL PROBLEMS

Two kinds of numerical problems interest the student and practicing analyst. One is predominantly theoretical in nature, and the other is even more predominantly practical in nature.

The first type of problem is essentially the application of simple physical chemistry to the systems being studied. Familiar topics involving ionic equilibria are solubility, solubility product, common and diverse ion effects, ionization, dissociation, pH, buffers, hydrolysis, complexation, instability, oxidation-reduction, and others. Such problems have long been considered basic in the more comprehensive texts on inorganic qualitative analysis. The subjects are equally important, of course, in quantitative analysis. The problems are largely theoretical.

The second type of problem deals primarily with the calculations which usually have to be made in the course of performing analyses. For example, direct-reading samples are weighed, vessels calibrated, titrants standardized, and amounts of desired constituents calculated. To be able to calculate the pH of a buffer system, the equivalence point of a given titration system, the instability constant of a complex, or the potential of an electrode in a given system, is very desirable; but to be able to make the calculations necessary for an analysis is indispensable if the results are to be useful. These problems are entirely practical in nature.

Incidentally, orientation tests of incoming graduate students have revealed that many such students are very deficient in solving the practical problems. One wonders if these individuals ever did any laboratory calculations.

Many years of teaching have convinced me that there is a very good correlation between the ability of a student to work numerical analytical problems and his understanding of quantitative analysis. Consequently, I have long made such problems a major part of my testing program.

THE TEACHER

The general outlook and training of the teacher have much to do with the success of courses in quantitative analysis. The blind cannot lead the blind, the ignorant cannot impart knowledge, nor can the uninterested generate interest. Often the teacher is one who majored and works in another area, but he was assigned the "quant" course because of necessity. He may never have done any real analyses of polycomponent systems, and probably he is unfamiliar with what is being done in industry. Out of this lack of background he states that gravimetric methods are passe, that burning carbon out of alloy steels at 1200°C is a "wet" method, and that we have only gravimetric, volumetric, and special methods of measurement. Or he writes that all samples must be dried, ground, and dissolved, although any experience with flue gas, water, and urine would have shown him that one does none of these operations with such materials.

There is considerable evidence that such deficiencies are too general for comfort. Perhaps the most serious need for beginning courses in quantitative analysis is for teachers who have analytical experience and knowledge, and who have a genuine sympathy for and interest in the subject.

Henderson's Dictionary of Scientific Terms. 7th Edition. *John H. Kenneth.* D. Van Nostrand Co. xv + 595 pp. $12.50.

The first edition of this excellent book was published in 1920, in Great Britain, covering the various subdivisions of Biology, listed as Botany, Zoology, Cytology, Genetics, Embryology, Anatomy and Physiology, and extended to include some terms in Bacteriology and Palaeontology. Each subsequent edition has expanded by inclusion of additional words, many of them new ones. This seventh edition lists more than 15,500 terms, in alphabetical order.

The book begins with lists of equivalents and abbreviations so as to make the definitions useful to Americans as well as residents of the British Isles. Although pronunciations differ at various places where this dictionary may be used, sound-symbols make clear the recommended forms. Workers in all of the listed sciences, including clerks and stenographers, should find this handy book invaluable.

THOMAS H. LANGLOIS

EARLY COMPREHENSION OF SCIENTIFIC CONCEPTS*

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The recent surge of interest in presenting scientific concepts to public school pupils before their high school years (Sci. Educ., 1960) increases the prospect of assuring an adequate supply of scientists for the future. It also anticipates the equally important need for a scientifically-oriented citizenry to support scientific progress in depth. In addition to these manifest advantages, the success achieved thus far in extending the teaching of basic scientific ideas to the early secondary and elementary levels has other implications, and it is these which stimulate the writing of this paper.

The journal, *Science Education*, has recently devoted an entire issue (March, 1960) to reporting progress in introducing ideas, hitherto reserved for much later periods in academic life, to selected and unselected groups of elementary and secondary school pupils. Among 16 papers on the subject in this issue, the majority deals with elementary education. Experiments of a similar nature are reported in other journals from the University of Illinois, the University of Indiana, Stanford University, the Massachusetts Institute of Technology, and a host of other institutions. At Berkeley, California, the municipal school authorities have created a special organization to study the success of a pilot program for elementary school children which has been undertaken with assistance from specialists from nearby universities. The possibilities presented by these practices for reorganizing school curricula and in changing certification requirements for teachers are immediately apparent. It is already evident that traditional notions about the receptivity of the young child must be revised (Garone, 1960). Suggested early introduction of nonscience concepts has also been made, with regard to philosophy, particularly.

The persistence of maxims referring to the importance of the early years, such as Jonathan Swift's, "Give me a boy until he is six, and you may do with him what you will," and, "As the twig is bent, the tree's inclined," is well known. They lend weight to the recognition of a fundamental principle which is clearly involved, but has lacked adequate, scientific support. What support has been forthcoming has been delayed by seemingly inordinate attention paid to maturation, critical stages, "late blooming," latency and other phenomena. The discovery (or rediscovery), that it does not appear to be necessary to delay the teaching of complex ideas until puberty or beyond, on the assumption that young minds are not "ready," impels a more penetrating examination of the educational sequence as a whole. To stimulate such an examination the following hypothesis is offered, with the realization that if results in accord with what has already been discovered further support it, a radical revision of our outlook upon educational practices is inevitable.

THE IMPORTANCE OF SUCCESSIVE EVENTS

If the life of an individual were represented along the abscissa of a graph, beginning with conception and ending with natural death, and on the ordinate were arranged arbitrary values for "the relative importance of events during life," based upon known but disconnected events from conception to death, a sloping line would be formed, high at the start and gradually diminishing in height until death (fig. 1). The precise slope of the line is open to question, but the diminishing

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magnitude of successive events in determining ultimate destiny is much less so. Evidence supporting this generality can be found in several fields of study:

(a) *Genetics and embryology.*—Conception, it goes without saying, is the occurrence which has the greatest effect upon events to follow. Some consequences of conception are incontestably paramount, such as the determination of sex, while others are recognizably deterministic within narrow limits (somatotype), and still others have wider limits of expression (temperament arising from somatotype). It is my contention that the underlying uniformity of events which are genetically determined has been obscured by over-attention to the extremes of variation. However, the extremes themselves can be used, if desired,

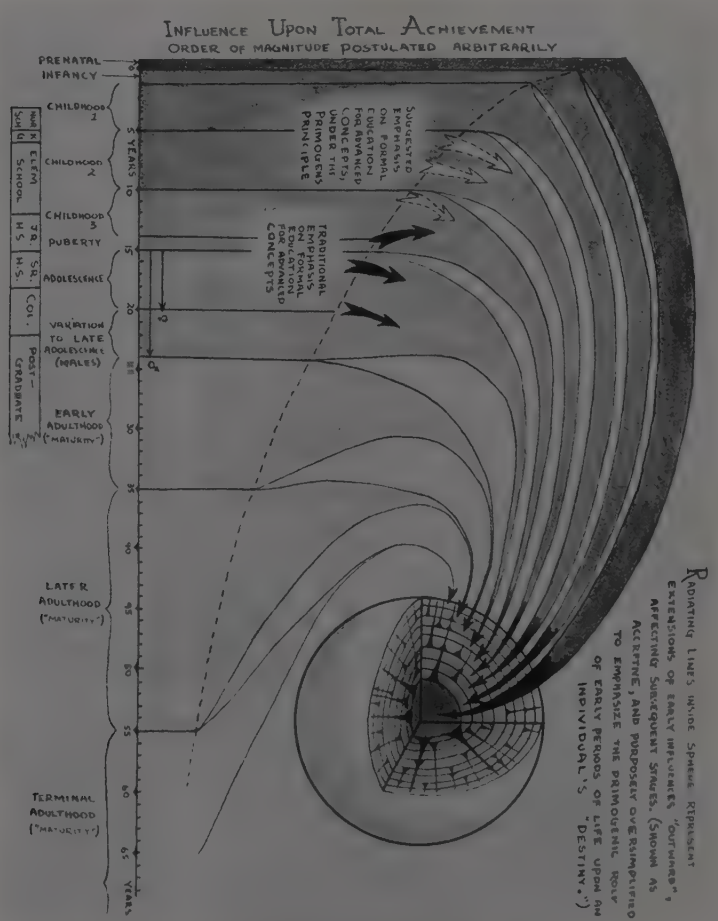

FIGURE 1. Diagram of the hypothetical effect of successive periods of life upon total accomplishments.

to support the thesis that determinism must be exceedingly high, and variations which have beclouded the issue are the result of extenuating circumstances that have preoccupied attention of some educators to the detriment of practical application of the core idea.

Following conception, the occasional but remarkable occurrence of monozygotic twinning lends support to the hypothesis that early events are the most important—what event, other than conception itself, could have a greater influence upon the development of an individual, than that of becoming two? Subsequent events are likewise influential; spina bifida, mongolian idiocy, and blebs leading to the condition known as lobster claw, point to the disastrous effects of early malfunctioning in utero (Stern, 1949).

L. W. Sontag and his co-workers at the Fels Institute have found that if the pregnant mother experiences severe emotional stresses during late pregnancy, her child is likely to be irritable, hyperactive, demanding of more frequent feedings, and "to all intents and purposes a neurotic infant when he is born" (Sontag and Richards, 1938). When it is realized that at eight weeks of age, the fetus (only an inch long) has developed so that reflexive movements can be elicited by tactile stimulation with a bristle, the depth of physiological affects later in fetal life seems much less surprising. These and other examples too numerous to mention emphasize the magnitude of early events in determing the ultimate product.

(b) *Parturition.*—"Normal" delivery covers wide differences between no difficulty and considerable difficulty. Using extremes to illuminate the hypothesis of a descending order of sequential events, it is evident that severe trauma with lasting effects can result from exceptionally difficult parturition, presumably due to compression of the fetus in passing through the birth canal, as well as anoxia producing a degree of damage to sensitive nervous tissue. Because measurement of the extent of damage is almost impossible, the effect of moderately difficult delivery upon the child must be regarded as an unknown but suspect quantity for the present. The extreme viewpoint of Rank (1952) is not adopted by most psychologists, but there is no denial that some effects last for a greater or lesser time. The critical question is the extent to which the nervous system has developed, a factor which itself may vary with inheritance. Many students of the subject attach no little importance to birth trauma.

The presumed degree of insecurity or anxiety arising from birth trauma would appear to have little or no connection with an individual's orientation toward science, yet the possibility that overt adult behavior related to hidden causes is a factor in facilitating the formation of "right" assumptions should not be ignored altogether. Severe preoccupation with anxiety, however caused, is bound to be an impedence to progress. On the other hand, when all that can be learned is known, it may be concluded that anxiety of a mild sort acts as a prod to discovering cause-and-effect relationships, and therefore anxiety can be a beneficial driving force of no small moment in fashioning an individual's future.

(c) *Studies of infancy and childhood.*—While the former belief that a child enters the world with a "clean slate" of behavior patterns has almost vanished, there is no positive and clear-cut means of measuring the effects of events in early infancy; only the vaguest outlines of responsive behavior (attitudes?) are presumed to be laid down. At the earliest time cause-and-effect relationships can be dealt with quantitatively, the profundity of early situations of certain types seems clear enough. The state of the mother's own orientation toward life appears to be clearly communicated to the offspring (Rank, 1952; Rank, B., 1950) (if the mother is poorly oriented, so are the offspring), and basic assumptions acquired by the individual under extreme deprivation in infancy suggests a continuum reaching into the "normal" acquisition of assumptions (Beres et al., 1950); that is to say, the "abnormal" testifies to the existence of effects in the "normal" by extrapolation. How valid extrapolation may be is again open to question. To disregard entirely what extrapolation may offer is to neglect possibilities of prime

importance. In other words, the circumstantial evidence that deeply-felt, traumatic experience is instrumental in developing an individualized, neurotic outlook upon the world can, as a working hypothesis, be arbitrarily inferred to apply with no less force to formal education and an individualized, *normal* outlook upon the world. The *early* educational experiences of children, by this reasoning, are the most influential ones in the academic sequence, and *if this be true the entire educational program deserves reorientation.*

That this principle transcends maturation is a conclusion reached through the same process of reasoning; indeed, the idea of maturation itself strengthens the argument that greater attention than ever should be directed toward perfecting the conditions of early education. As a postulate, the elementary school and secondary school teachers should be not *less* well educated than those in the higher levels, but actually *better* prepared, for their influence probably has a deeper and longer lasting effect.

(d) *Psychiatry.*—It is well known that psychiatrists encourage their patients to delve into the distant past in order to come to grips with all-but-forgotten experiences. Held up to the light of adult perspective, these searing, traumatic events, having had so deep an effect upon the patient as to create intolerable tensions, can then be comprehended by them, with successful adjustment in some cases. When hypnosis is resorted to, a considerable degree of success attends the technique of having the subject "regress" into childhood. The depth and history of troublesome basic assumptions are thus revealed, and the way is open for efforts to treat the patient intelligently.

(e) *Criminology.*—It is again the exceptional and unusual which enlighten us about the general principle, when one observes the effects, for example, of "broken homes" or dissention within the home, upon the course of action followed by children coming from such homes. That social responsibility is undergoing critical development in childhood and adolescence is further indicated by the information that among all male youths classed as delinquents in the United States, only five percent have been Boy Scouts (Hoover, 1959). The desirability of constructive youth organizations—one is tempted to say, the need for compulsory membership in such organizations—is apparent. Behavior patterns at this time do not seem to override early experience so much as they fall into line with the principle here offered.

THE "PRIMOGENS" PRINCIPLE

Drawing upon exceptional circumstances, such as those described briefly above, there appears to be a thread of continuity perceivable. While it has been axiomatic ("The boy is father to the man") that a cause-and-effect relationship can be traced backward to childhood and infancy from adolescent and adult achievements, both "good" and "bad," there has not appeared to be a full realization of what this implies educationally. It is for this reason that the current interest in presenting scientific concepts earlier in the school sequence than tradition has dictated comes as something of a surprise.

What has been lacking is a concise, verbal expression of this principle. Lack of such an expression has impeded the focussing of attention upon the earliest years of life by all but a small group of specialists who see their importance with fair clarity. The term, "primogens," meaning "early beginning," is therefore suggested as a word useful in calling attention to the importance of early events. The primogens principle may then be defined as a statement of the general relationship of sequential events during life from which it can be postulated that each successive period of life has less and less influence upon the ultimate destiny of the individual.

Exceptions may leap to mind, such as blindness occurring in middle life and altering the individual's destiny profoundly. But closer examination of such an unfortunate accident may reveal that whatever early adjustments were or

were not made prior to that time will constitute the degree to which the person successfully copes with the event (Montagu, 1955). Thus what appear to be exceptions may actually cast further light upon the extensiveness of this principle. If we can reorient our thinking to regard maturation and other critical periods in life as riffles along the descending stream of influential events in life, it is likely that the proper perspective will ensue.

APPLICATION OF THE PRINCIPLE

Early comprehension of scientific concepts becomes less of a striking discovery in education, in the light of the primogens principle, and more of a natural exploitation of the potential of individuals.

Following the primogens principle to its conclusion, we can appreciate the tremendous importance of having excellent teachers in the *earliest* stages of education. Everyone of us can probably trace our keen interest in our present endeavors to parents or teachers influencing us very early to cherish curiosity, to love accuracy, and to extend our knowledge of the world about us. If this concept is soundly based, the kindergarten and elementary school become the focus of far greater attention than they have been in the past. Rather than relegating kindergarten and elementary school teachers to a relatively minor role, therefore, teaching in the early levels should confer upon teachers the handsomest rewards of pay and prestige! And the satisfactions springing from having a greater assurance of "academic immortality" will be rewards themselves.

The traditional view—that the best teachers are to be reserved for the higher levels—must be softened at least to the extent that those having proficiency in science and arts, with full cogency of their importance in the academic sequence, and convinced of the validity of the primogens principle, are lured into the *lower* levels of education. Teachers in the lower grades should be well versed in psychology (beyond a single, introductory course), and should themselves be lively, dynamic persons, fully receptive to advanced developments in their field. They should be capable of encouraging curiosity, exploring avenues suggested by pupils' contributions to an "I wonder" box (Bohnhorst and Hosford, 1960), for example, and creating attitudes with the greatest "primogenic" effect. In short, they should not be trained to teach subjects, only, but to teach human beings.

Ultimately, with so propitious a start, able pupils as well as the less gifted would reach, at a much earlier age, that enviable state of education, *self-education*, that is so conspicuous by its absence among a large proportion of our college students today (Pettit, 1960).

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CYCLIC-FLUCTUATION METHODS FOR DETERMINING PERMEABILITY AS APPLIED TO VALLEY-TRAIN DEPOSITS IN THE MAD RIVER VALLEY IN CHAMPAIGN COUNTY, OHIO[1]

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INTRODUCTION

As a part of the cooperative program with the Ohio Department of Natural Resources, Division of Water, the U. S Geological Survey is making an investigation of the ground-water resources of Champaign County, Ohio It was deemed important to future water-resources development in the Mad River valley in Champaign County to have information on the hydraulic properties of the valley-train deposits Unfortunately, so few wells exist in the area that ordinary pumping-test methods seldom can be used to obtain this information In the vicinity of Urbana, however, there is a shallow observation well, screened in the valley-train deposits. The fluctuations of water level in this well reflect corresponding changes in stage in the nearby Mad River. Ferris (1952) shows that observations of the lag, velocity, and wave length of sinusoidal changes in ground-water level, such as are produced by similar changes in stream stage, can be used to determine the transmissibility coefficients of aquifers.

I compared the results of the cyclic-fluctuation methods with pumping-test data from the Urbana well field and laboratory determinations of permeability. The pumping-test data were made available by E. J. Schaefer, Consulting Hydrologist, Columbus, Ohio. The laboratory determinations were made by the U. S. Geological Survey's Hydrologic Laboratory, Denver, Colo.

The purpose of this paper is to demonstrate how, by using only one observation well and assuming a single point of offshore recharge, a reasonably accurate value of transmissibility can be obtained.

Geography

The Mad River flows from north to south across the approximate center of Champaign County, Ohio. The valley in the vicinity of Urbana is bounded on the west by till plains. On the east, "high level" outwash-plain deposits join the "low level" valley-train deposits at several points. The relief between the two deposits is approximately 40 ft. Both deposits are considered together and are hereafter referred to as the valley-train deposits (fig. 1). Both deposits are of Wisconsin (Glacial) age, the lower level deposits consisting primarily of reworked material from the slightly older higher level deposits.

Definition of Terms

The field coefficient of permeability may be defined as the number of gallons of water a day that percolates, under prevailing conditions of water temperature, etc., through each mile of water-bearing bed under investigation (measured at right angles to the direction of flow), for each foot of thickness of the bed, and for each foot per mile of hydraulic gradient (Wenzel, 1942).

The coefficient of transmissibility is the field coefficient of permeability times the thickness of the aquifer, in feet, it may be defined as the number of gallons of water that will move in 1 day through a vertical section of the aquifer 1 mile wide, having a height equal to the full thickness of the aquifer, under a hydraulic gradient of 1 ft per mile (Meinzer, 1923).

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[1]Publication authorized by the Director, U. S. Geological Survey.

The coefficient of storage under water-table conditions is very nearly, though not exactly, equal to the specific yield, which is defined as the ratio of the volume of water that will drain by gravity from a saturated rock to the total volume of the rock (Meinzer, 1923).

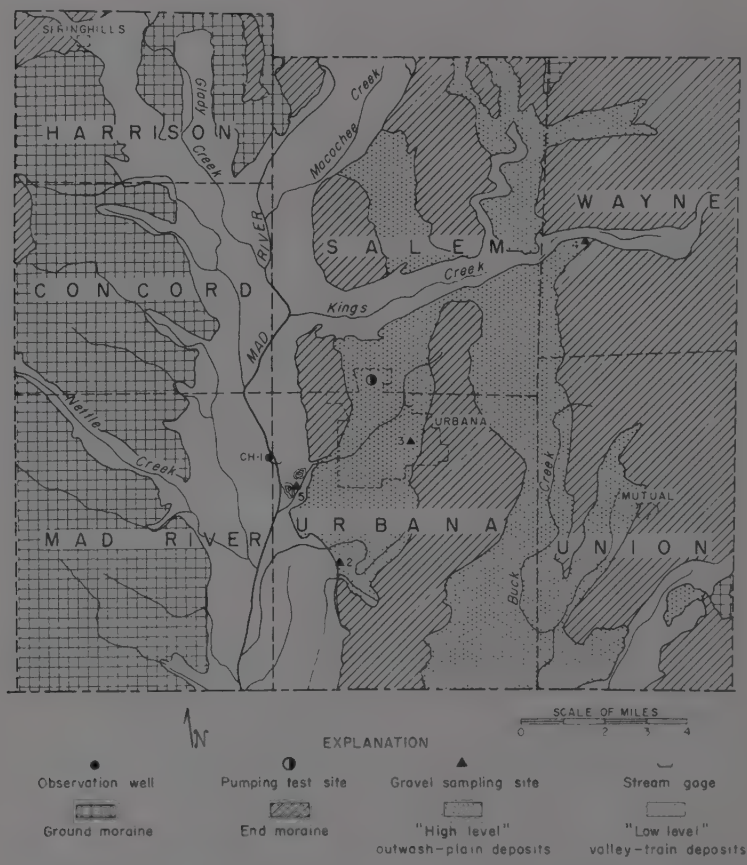

FIGURE 1. Map of the central part of Champaign County, Ohio, showing the extent of the valley-train deposits and location of wells, gravel-sampling sites, and stream gage. (Pleistocene geology generalized from unpublished map by R. P. Goldthwait.)

CYCLIC-FLUCTUATION METHODS

The methods used here were adapted from the work of Ferris (1952), who states "As the stage of the surface water rises, the head upon the subaqueous outcrop of the aquifer increases and thereby either increases the rate of inflow to the aquifer or decreases the rate of outflow therefrom. The increase in recharge or reduction in discharge results in a general recovery of water level in the aquifer."

Ferris applied the cyclic-fluctuation method to fluctuations of the river stage and observation-well levels along the Platte River at Lincoln, Nebr. In Ferris'

example three observation wells were used and fluctuations on both the rising and the falling stage were used. In this study the cyclic fluctuations of water levels in the Mad River and one observation well, Ch-1, were tabulated. The method of Ferris was applied only to the ratio of rise of water level in the observation well to the corresponding stream rise. This was done because the stream was not controlled as it was in Ferris' original work; instead, the stream stage rose quickly but took a relatively long period to decline.

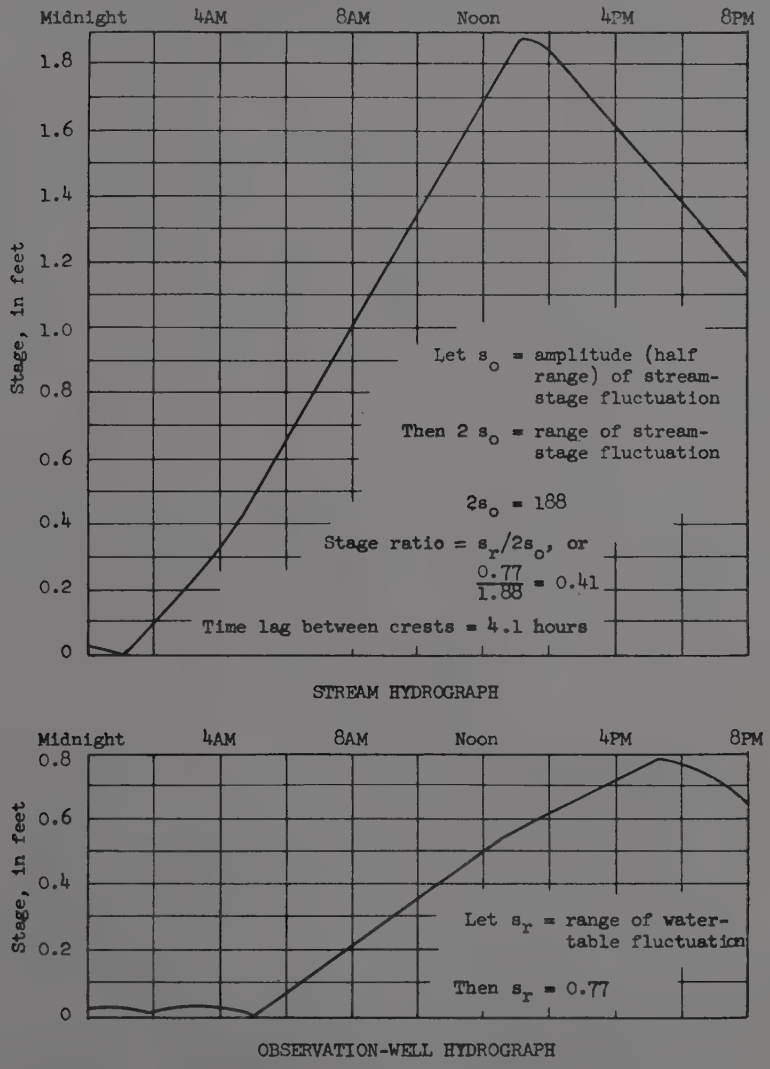

FIGURE 2. Generalized and expanded graph showing stream-stage fluctuation, observation-well fluctuation, and methods used to obtain stage-ratio and time-lag figures.

The observation well, Ch-1, is 155 ft west of the Mad River and approximately 100 ft upstream from a gaging station operated by the U. S. Geological Survey. The well, which was constructed as an observation well by the Ohio Division of Water, is 45 ft deep, is cased to the bottom, and is drilled in valley-train deposits.

Ten periods in which there were rises in stream stage and corresponding rises in water level in the observation well were chosen. These periods were selected when there was no appreciable rainfall in the area and when the river was free of ice. The rises resulted from rainfall in the headwaters area of the river. The average ratio of ground-water fluctuation to river change was computed, as was the average time lag between corresponding crests in the stream and in observation well Ch-1. Figure 2 shows, on an expanded scale, a typical stream rise, the corresponding rise in the observation well, and the methods used to obtain figures used in the calculations.

Stage-Ratio Method

In the stage-ratio method, use is made of the ratio of ground-water fluctuation to stream-stage change. This ratio, as worked out for the stream gage on the Mad River near Urbana and observation well Ch-1, averages 0.41 (see example on fig. 2). As stated previously, this ratio is based on the rising stage and not the falling stage. Ferris' original work averaged both the rise and fall, since flow in the stream used in the Platte River tests was controlled by discharge from a dam upstream. As indicated in the equation below it is necessary that S, the coefficient of storage, be known in order to evaluate T, the coefficient of transmissibility. A reasonable estimate of S can be made because it is known that the aquifer is nonartesian. The formula, in units of gallons per day per ft, as set up by Ferris is:

$$4.4\left(\frac{S}{t_o T}\right)=\left[\frac{-\log_{10}(s_r/2s_o)}{x}\right]^2$$

The logarithmic quantity $(s_r/2s_o)$ is in effect the ratio of the range of ground-water stage to the range of river or tide stage. Thus the right-hand member of the above equation represents the slope of this plot, and if the change in logarithm of the range ratio is selected over one log cycle then the numerator of this slope expression reduces to unity. Then:

$$4.4\left(\frac{S}{t_o T}\right)=\frac{1}{\triangle x} \qquad \text{or:}$$

$$T=\frac{4.4\ \triangle x^2}{t_o} S$$

Where:

T = coefficient of transmissibility [gal/(day·ft)]
S = coefficient of storage (dimensionless)
t_o = period of uniform tide or stage (days)
x = distance (ft) from suboutcrop to observation well
$\triangle x$ = change in logarithm of the range ratio over one log cycle

The period of river fluctuation on the rising limb of the cycle ranged from 9 to 18 hr and averaged 12 hr. Assuming that the falling limb of the cycle would have been the same if streamflow could have been controlled, the period of river fluctuation would equal approximately 24 hr.

Using the average figure of 0.41 for the ratio of ground-water stage to river stage, we can construct a semilogarithmic plot of this ratio versus distance from the river (fig. 3). Using the $\triangle x$ value indicated for one log cycle, and $t_o = 1$ day, and assuming various values of S which are reasonable for water-table conditions, the equation is:

$$T = \frac{4.4\ (470)^2}{1} S \text{ or } 970{,}000\ S$$

$T = 97{,}000$ if $S = 0.10$
$T = 150{,}000$ if $S = 0.15$
$T = 190{,}000$ if $S = 0.20$
$T = 240{,}000$ if $S = 0.25$

The negative value shown on figure 3 represents the effective distance to the offshore outcrop, which is assumed to be half the stream width, 27 ft. This assumption introduces a possible factor of error into the calculations, which in this investigation is thought to be less than 10 percent.

Time-Lag Method

Because there is no large withdrawal of water from the valley-train deposits along the Mad River or any other distorting factors to affect the observation well, variations in the lag between the peak period of stream rise and the peak period of well rise can be attributed to difficulty in reading the compressed time scale of the water-level recorders or to inadequate knowledge of the exact effective distance

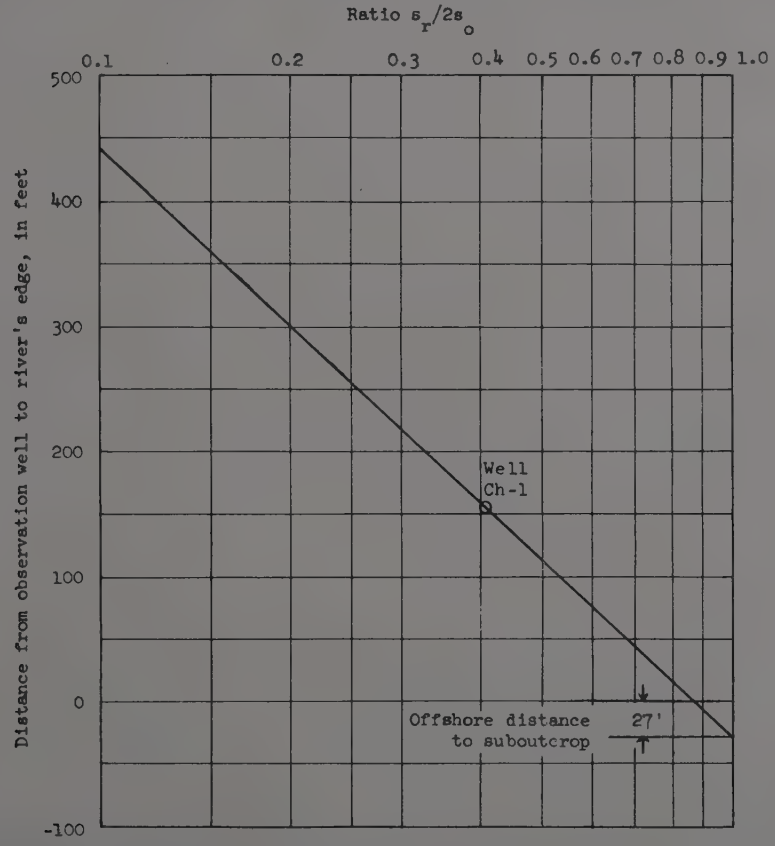

FIGURE 3. Semilogarithmic plot of the ratio of ground-water stage to stream stage versus the distance of the observation well from the cyclic stream.

to the offshore outcrop. The average period of time lag, t_l, between the maximum stage of the Mad River and the maximum ground-water stage is 4.1 hr (fig. 2). This time lag is plotted against distance, in ft, from the observation well to the river's edge (fig. 4). Again assuming that the effective distance to the offshore outcrop is 27 ft, and using the formula of Ferris we obtain T in units of gallons per day per ft, using t_o and t_l in days.

$$T = \frac{0.60\ x^2\ t_o}{t_l^2} S$$

Substituting values obtained from figure 4, the equation becomes:

$$T = \frac{0.60\ (155)^2\ 1}{(3.5/24)^2} S \text{ or } 690{,}000\ S$$

Again assuming the various values for S under water-table conditions we get:

T = 69,000 if S = 0.10
T = 100,000 if S = 0.15
T = 140,000 if S = 0.20
T = 170,000 if S = 0.25

The difference in the coefficients of transmissibility indicated by the two methods used is probably due to a lack of sufficient information for proper appraisal of the suboutcrop distance or to inadequacies in reading the compressed scale of the recorder graphs.

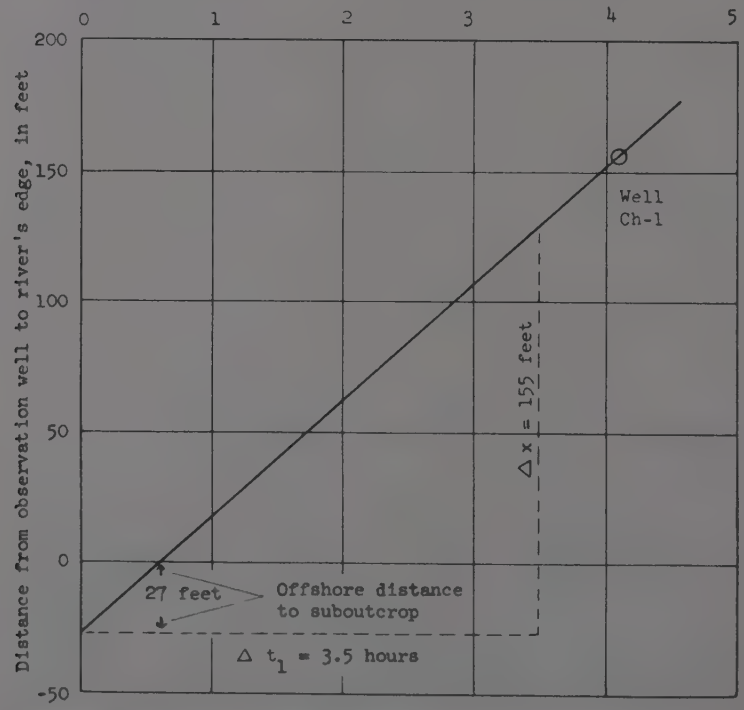

FIGURE 4. Plot of time lag versus distance of observation well from suboutcrop.

Average of Cyclic-Fluctuation Methods

The results of the two methods are summarized as follows:

Method	T, coefficient of transmissibility, in gal per day per ft			
Assumed coefficient of storage	0.10	0.15	0.20	0.25
Stage-ratio method	97,000	150,000	190,000	240,000
Time-lag method	69,000	100,000	140,000	170,000
Average (rounded)	83,000	120,000	160,000	200,000

The saturated thickness of valley-train deposits at observation well Ch-1 is approximately 40 ft. Using this thickness and the average values from the data given above, the average field permeability, in gallons per day per ft^2, is found by dividing the coefficient of transmissibility, in gallons per day per ft, by the saturated thickness of the aquifer, in feet.

The field-permeability values, using each of the average values given previously, are:

Coefficient of storage	Field coefficient of permeability in gal per day per ft^2
0.10	2,000
0.15	3,000
0.20	4,000
0.25	5,000

PUMPING-TEST DATA

A pumping test was made in 1956 for the city of Urbana by E. J. Schaefer, Consulting Hydrologist, Columbus, Ohio. The municipal well field is just north of Urbana in the "high level" outwash-plain deposits approximately 3 miles east of the Mad River (fig. 1).

Schaefer's computed value of T, the coefficient of transmissibility, using one pumped well and one observation well, was 222,000 gal per day per ft. He computed the value of S, the coefficient of storage, in the same test as 0.14. The saturated thickness of material in the area of the well field is approximately 50 ft which, divided into the coefficient of transmissibility calculated from the test data, gives a field coefficient of permeability of approximately 4,400 gal per day per ft^2.

LABORATORY ANALYSES

Five samples of the valley-train and outwash-plain deposits were collected and sent to the U. S. Geological Survey's Hydrologic Laboratory, Denver, Colo., where determinations were made of porosity and permeability.

Figure 1 shows the location of four of the sampling sites. The fifth sampling site, No. 1, was a gravel pit just west of the Mad River, near Eagle City, in Clark County, approximately 3 miles south of the Champaign County border.

Presented below in tabular form are the sample number, field description of location, and the porosity and coefficient of permeability as determined in the laboratory. The laboratory, or standard, coefficient of permeability is the same as the field coefficient except that it is determined at 60° F. The average temperature of the ground water in the Urbana area is a little less, but not enough to make a substantial difference when comparing field and laboratory data.

TABLE 1

Sample number	Field description of location	Porosity (% voids)	Coefficient of permeability gal/[day·ft²]
1	Gravel pit near Eagle City, Ohio	23.7	4,500
2	Valley wall south of Urbana, Ohio	32.6	6,000
3	Gravel pit, east edge of Urbana, Ohio	36.3	4,500
4	Gravel pit near Cable, Ohio	26.4	3,400
5	Gravel pit, west edge of Urbana, Ohio	40.3	2,000

Averages of all values give a porosity of 31.8 percent and a coefficient of permeability of 4,100 gal per day per ft².

SUMMARY AND CONCLUSIONS

The cyclic-fluctuation methods, using only one well and assuming the coefficient of storage to be about 0.2, gives values of the coefficient of permeability that are in reasonable agreement with values obtained by both of the other methods used. Because the coefficient of storage under water-table conditions usually is between 0.1 and 0 3, it is probable that the value of the valley-train deposits is not far from 0.2. Analysis of the pumping-test data collected by E. J. Schaefer gives a permeability of 4,400 gal per day per ft² for what probably are very similar deposits. The average figure for the laboratory determinations of the coefficient of permeability, also for probably similar deposits, is 4,100 gal per day per ft². Each of these independent methods of arriving at the coefficient of permeability agrees well with the cyclic-fluctuation method, which gave a figure of 4,100 gal per day per ft² using a storage coefficient of 0.2.

The permeability of the valley-train deposits in Champaign County, Ohio, may vary over a wide range but probably is in the general vicinity of 4,000 gal per day per ft² wherever well-sorted sand and gravel make up the deposits.

The cyclic-fluctuation method as described here promises to be useful in water-resources investigations, in that it can be applied to stream fluctuations and their effect on ground-water levels in areas having only a single observation well. An error, of course, is introduced by assuming the position of the single line of recharge, but if the stream is relatively narrow and the observation well is located at a comparatively large distance the error involved is small. The agreement among the three independent methods of analysis of the hydrologic data indicates that this method is applicable in the area studied, and by inference in other areas of similar hydrology. Checking of the method in other areas would be desirable, but even without checking it appears that the method is useful in situations where pumping tests are impractical.

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THE EFFECT OF pH ON THE ABSORPTION OF Sr^{89}, P^{32}, AND Fe^{59} IONS BY LEAVES OF *ZEA MAYS*[1]

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INTRODUCTION

Factors affecting the foliar absorption of cations, anions, and organic molecules have been studied intensively in recent years. The need for such information for studies on the foliar application of herbicides and fungicides, and the availability of radioactive labels for these chemicals have stimulated this research. Detailed information concerning the foliar absorption of specific ions or molecules and their absorption by particular species is still lacking, however. Moreover, the physiological explanation for some phases of the absorption process is largely unknown. The subject of foliar absorption has been recently reviewed by several authors (Boynton, 1954; van Overbeek, 1956; Wittwer and Teubner, 1959).

The hydrogen ion concentration of solutions of both ions and polar solutes applied to the foliage of plants has been considered an important factor in absorption (Orgell, 1954). Orgell (1957) reported that acidic substances were "sorbed" in greater amounts by excised cuticle disks as the pH of the surrounding solution was lowered from 7 to 1. For basic chemicals "sorption" increased as the pH was raised from 3 to 9. Studies on anion absorption by leaves have been largely confined to forms of phosphate. Low pH values of approximately 2 to 3 have brought about increased absorption of phosphate solutions compared to rates of uptake at or near neutrality (Swanson and Whitney, 1953). Little information is available on the effect of pH on the absorption of other anions with the exception of sulfate. Biddulph et al. (1956) found little effect of pH on the absorption of sulfate by bean leaves. Koontz and Biddulph (1957) found that the sodium salt of phosphate was translocated in greatest amounts from the leaf of red kidney bean to which it had been applied at a pH just below 5. For the potassium salt a pH of about 8 was optimum. This study did not give data for pH values of pH 4 or lower. Teubner et al. (1957) reported that the phosphate or citrate salts of K^{42} and Rb^{86} are absorbed most rapidly at pH 8.

This study is a contribution on the effect of pH on the absorption of ions of phosphorus, strontium, and iron by leaves of *Zea mays* L., a species not previously studied in this regard.

MATERIALS AND METHODS

Five grains of corn (Minhybrid 803) were sown per 4-inch pot in soil consisting of 2 parts silt loam to 1 part sand. Following germination and subsequent growth for 10 days in a greenhouse set at 70°F, seedlings were thinned to 3 per pot and treated.

Solutions of phosphorus-32, iron-59, and strontium-89 were prepared having an activity of 0.6 $\mu c/\lambda$ at a pH of 2.5, 3.0, 4.5, 7.0, and 8.2. The radioisotopes were obtained from the Oak Ridge National Laboratory as $FeCl_3$, $SrCl_2$, and H_3PO_4.

A 0.1 M citrate-phosphate buffer with citric acid and dibasic sodium phosphate was used to obtain pH 2.5 and 4.5. The pH of the distilled water is 3.0 and a

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[2]Research Associate and Associate Professor, respectively, Department of Plant Pathology and Botany, University of Minnesota.

0.1 M phosphate buffer with monobasic and dibasic sodium phosphate was used to make solutions of pH 7 and pH 8.2 (Colowich and Kaplan, 1955).

The plants were treated by placing 10-λ drops of the isotope solution containing 0.6 μc on the upper side of the second leaf of each corn plant. Three pots, each with three plants, were treated with each isotope at each pH. The application of the radioisotope took approximately 4 hours, and the plants were harvested in the reverse order of treatment to insure equal uptake time.

All parts of each plant but the roots were harvested, 24 hours after treatment. Each plant was separated into four morphological parts: the basal leaf was called the first leaf; the one above it the second leaf; the third leaf; and the fourth leaf including the shoot apex (fig. 1, harvest plan). All similar morphological parts from all three plants of each pot were counted together. The area to which the isotope was applied to the second leaf was removed at harvest and was not counted with the rest of the second leaf.

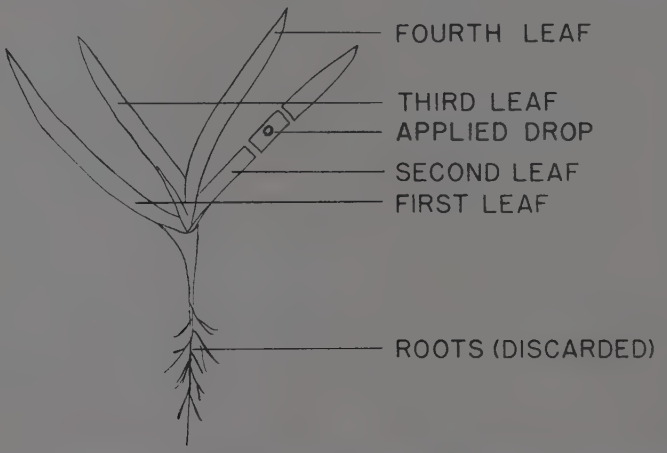

FIGURE 1. The harvest plan. The corn plants were divided into the parts as shown and all parts assayed for radioactivity except the roots. The rectangular area around the applied drop of the radioactive solution was removed before the second leaf was assayed.

The data were analyzed by means of analysis of variance. An analysis was designed to reveal whether there were differences in total uptake of isotope as a result of the pH of the applied solution, and a second analysis was made to evaluate the differences in accumulation of each radio-element in individual parts as affected by pH.

RESULTS AND DISCUSSION

Counts in the entire plants (table 1) at the pH values 2.5 and 4.5 are higher than for other pH values and in each case they are part of a nonsignificant group. Mean counts for pH 3.0 are in all cases intermediary, and in general mean counts for the pH values 7.0 and 8.2 are consistently lower than the others. In table 1 are total mean counts per minute per plant for all three isotopes. The counts are arranged in descending order of magnitude. For each of the three isotopes, differences in counts per minute among pH values were significantly different. In all three experiments these differences were significant at both the 0.05 and the 0.01 levels.

A Student-Newman-Kuehls Multiple Range Test was made on each array of means from analysis of variance and nonsignificant groups of means isolated. Brackets in table 1 enclose nonsignificant groups of means.

Relatively little phosphorus-32 moved downward in the plant and from the analysis of variance it is concluded that the difference in this movement due to pH was not significant. Significantly different amounts were taken up and a multiple range test of the means for the second leaf indicates that the pH levels 4.5 and 2.5 in almost all cases are significantly higher than the others.

Table 2 contains counts per minute per plant part for all pH values of the

TABLE 1

Total mean counts per minute per corn plant of P^{32}, Fe^{59}, and Sr^{89} at various pH values together with F ratios from analysis of variance

Phosphorus-32			Iron-59			Strontium-89		
counts/min	0.05[a]	0.01[a]	counts/min	0.05	0.01	counts/min	0.05	0.01
pH 4.5 5944			pH 4.5 1075			pH 2.5 4249		
pH 2.5 5458			pH 2.5 963			pH 4.5 3703		
pH 3.0 4015			pH 3.0 584			pH 3.0 2185		
pH 8.2 3635			pH 7.0 470			pH 8.2 1319		
pH 7.0 3066			pH 8.2 31			pH 7.0 884		
F = 10.816**[b]			F = 43.715**			F = 28.699**		

[a]Probability levels; brackets enclose groups of nonsignificant means.
[b]Analysis of variance F ratios; ** indicates significance at both the 0.05 and 0.01 levels.

TABLE 2

Mean counts per minute of phosphorus-32 in various parts of 10-day-old corn and at various pH values, together with F ratios from analysis of variance

1st leaf			2nd leaf			3rd leaf			4th leaf and apex		
counts/min	0.05[a]	0.01	counts/min	0.05	0.01	counts/min	0.05	0.01	counts/min	0.05	0.01
pH 4.5 103			pH 2.5 3003			pH 4.5 698			pH 4.5 245		
pH 2.5 58			pH 4.5 2687			pH 2.5 442			pH 2.5 202		
pH 3.0 41			pH 3.0 2240			pH 7.0 250			pH 3.0 150		
pH 7.0 36			pH 8.2 2057			pH 3.0 233			pH 8.2 133		
pH 8.2 27			pH 7.0 1643			pH 8.2 224			pH 7.0 114		
F = 10.816**[b]			F = 3.876*			F = 14.544**			F = 13.006**		

[a]Probability level; brackets enclose groups of nonsignificant means.
[b]*significance at the 0.05 level and ** significance at the 0.01 level.

radioactive phosphorus-32. The table is arranged in descending order of magnitude of counts, with separate values for each morphological entity. Movement of the isotope into the first leaf, following absorption of the isotope by the second leaf, is downward in the plant, while movement into the third and fourth leaves is upward. Analysis of variance for the second leaf indicated significant differences only at the 0.05 level, with the means falling into two large groups of nonsignificant means. In all other instances F ratios indicated significance at both the 0.05 and 0.01 levels and the multiple range tests indicated several smaller

TABLE 3

Mean counts per minute of iron-59 in various parts of 10-day-old corn and at various pH values, together with F ratios from analysis of variance

1st leaf		2nd leaf		3rd leaf		4th leaf and apex	
counts/min							
0.05[a]	0.01	counts/min 0.05	0.01	counts/min 0.05	0.01	counts/min 0.05	0.01
pH 2.5 9		pH 4.5 585		pH 4.5 125		pH 2.5 353	
pH 4.5 7		pH 2.5 517		pH 2.5 84		pH 4.5 343	
pH 3.0 6		pH 3.0 355		pH 7.0 68		pH 3.0 182	
pH 8.2 3		pH 7.0 255		pH 3.0 41		pH 7.0 144	
pH 7.0 3		pH 8.2 15		pH 8.2 3		pH 8.2 10	
F = 1.415		F = 22.660**[b]		F = 11.192**		F = 14.622**	

[a]Probability level; brackets enclose groups of nonsignificant means.
[b]* significance at the 0.05 level and ** significance at the 0.01 level.

TABLE 4

Mean counts per minute of strontium-89 in various leaves of 10-day-old corn and at various pH values, together with F ratios from analysis of variance

1st leaf		2nd leaf		3rd leaf		4th leaf and apex	
counts/min				counts/min		counts/min	
0.05[a]	0.01	counts/min 0.05	0.01	0.05	0.01	0.05	0.01
pH 4.5 4		pH 2.5 4241		pH 7.0 9		pH 7.0 6	
pH 2.5 2		pH 4.5 3693		pH 2.5 6		pH 3.0 5	
pH 8.2 1		pH 3.0 2175		pH 4.5 5		pH 4.5 2	
pH 3.0 1		pH 7.0 1313		pH 3.0 4		pH 8.2 1	
pH 7.0 1		pH 8.2 868		pH 8.2 3		pH 2.5 —	
F = 1.557		F = 8.649**[b]		F = 0.378		F = 2.623	

[a]Significance level; brackets enclose groups of nonsignificant means.
[b]**significance at the 0.05 and 0.01 levels.

groups of nonsignificant means. For the first leaf, pH 4 was isolated as the only mean that differed significantly from the rest, while in the third and fourth leaves more groups appear. It is evident from the array of data that more often than not the pH values 2.5 and 4.5 significantly enhanced uptake and subsequent movement more than the others.

The uptake and movement of strontium-89, as deduced from the data of table 4, differ considerably from those of both phosphorus-32 and iron-59. In terms of counts, more strontium is taken into the second leaf of the plant treated with it than either phosphorus or iron into the second leaves of the plants treated with them, respectively, and less strontium-89, in comparison, is moved out of this locality. The effect of pH on uptake is given in the second leaf portion of table 4 and indicates that differences due to pH are significant. The groups of nonsignificant means for uptake are less well defined than with phosphorus and iron. Not only did a small amount of isotope move into the third and fourth leaves, but the amount of strontium-89 that moved was nonsignificant with respect to pH.

TABLE 5

The effect of pH on the percentage of P^{32}, Fe^{59}, and Sr^{89} translocated from the "applied leaf" to the rest of the corn plant

	Phosphorus-32 activity in counts/min by pH			
	2.5	4.5	7.0	8.2
Total activity in plant minus "applied leaf"	702	1047	400	384
Total activity in plant	5458	5944	3066	3635
% of total activity translocated	12.8	17.6	13.0	10.6
	Iron-59 activity in counts/min by pH			
	2.5	4.5	7.0	8.2
Total activity in plant minus "applied leaf"	446	717	215	16
Total activity in plant	963	1075	470	31
% of total activity translocated	46.3	66.7	45.7	52.2
	Strontium-89 activity in counts/min by pH			
	2.5	4.5	7.0	8.2
Total activity in plant minus "applied leaf"	8	10	16	15
Total activity in plant	916	3703	884	132
% of total activity translocated	0.87	0.3	1.8	0.40

The total amount of each radioisotope absorbed at any given pH varied; the most activity recorded was for phosphorus-32, next, for strontium-89, and least activity for iron-59. Since the actual activity counted depends partly on the counting efficiency, no direct comparisons of relative absorption among these three radioisotopes can be made. The efficiency of counting for the gamma emission of iron-59 is low compared to the counting efficiency for the other two isotopes and this may, in part, account for the lowest values for the activity in the radio-iron group. Some estimation of the relative rates of translocation of the three radioisotopes can be made, however. In table 5 are given the percentage values for the amounts of each radioisotope translocated from the "applied leaf" to the rest of the plant. This value is obtained by dividing the total activity in the plant by the total activity minus the activity in the "applied leaf." The amount of transport of strontium-89 under the conditions of the experiment is very small. With the exception of the plants which received strontium-89 at pH 7.0, less than 1 per cent of the total activity found in the plant was translocated out of the "applied leaf." For the radioisotopes of phosphorus and iron, the greatest

translocation occurred among the plants receiving the radioisotope at pH 4. Relatively little difference in translocation occurred at pH 2.5, pH 7.0, or pH 8.2 for both radio-iron and radio-phosphorus.

Since pH may directly affect the amount of radioisotope absorbed by the leaf, this in turn would affect the amount of the element available for movement through the leaf blade. The amount of any particular element which reached the terminal phloem cells would be affected indirectly by the pH-dependence of the absorption mechanism at the leaf surface. Due to the buffer capacity of the non-conducting cells of the leaf as well as those of the phloem, it seems unlikely that the hydrogen ion concentration exerted any effect beyond the cells in the immediate vicinity of the application area. It is assumed here that the phloem cells are the main conductive tissue for translocation of these radioisotopes (Linck and Sudia, 1959: Swanson and Whitney, 1953).

SUMMARY

The absorption and translocation of phosphorus-32, iron-59, and strontium-89 by the leaves of 10-day-old corn plants were studied as functions of pH. The pH of the solution in which the mineral ion is supplied to the corn plants had a significant effect on absorption. For the three mineral ions studied, greater absorption occurred at the lower pH values of 2.5 and 4.5 and significantly lower amounts were absorbed at the higher pH values of 7.0 and 8.2.

All three mineral ions are readily absorbed by the leaves of corn but they differ markedly in the amount of each ion transported from the leaves. For the isotope of phosphorus, between 10 and 18 percent of the total activity in the plant is found in the stem and leaves following transport from the "applied leaf." These figures can be compared to from 45 to 67 percent of the iron translocated. Less than 2 percent of the radio-strontium was transported from the "applied leaf."

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DRAINAGE DEVELOPMENT, SOUTHERN SACRAMENTO MOUNTAINS, NEW MEXICO

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INTRODUCTION

Field mapping some years ago in the Surveyors Canyon area of the southern Sacramento Mountains, New Mexico, revealed an unusually well-developed set of barbed tributaries. Later visits to adjoining areas, and a study of topographic maps and air photographs, have disclosed many other evidences of stream capture and diversion. Several of these features are described in this paper, and suggestions as to the evolution of the drainage are presented.

The origin and significance of the features described have been discussed with Lloyd C. Pray and Richard P. Goldthwait, to whom I express appreciation.

GEOLOGIC SETTING

The Sacramento Mountains of south-central New Mexico are an asymmetrical north-trending fault block of Paleozoic sedimentary rocks (fig. 1), bounded on the west by a zone of normal faults. They constitute the southeasternmost unit of the Basin and Range physiographic province. The summit of the range stands some 4,300 ft above the Tularosa Basin, a large graben floored with Quaternary alluvium. Displacement on the boundary fault zone is at least 7,000 ft (Pray, 1954), and may be considerably more.

Extending southeast from the central part of the range is a zone of sharp monoclinal folding and normal faulting. This was shown by Darton (1928, pl. 44) as a continuous fault, and it has been termed the Sacramento River fault. Maximum displacement along this zone is estimated at 1,000 ft. The zone is *en echelon* with the major boundary fault of the range and with that of the Guadalupe Mountains some 25 miles to the southeast; and it shows the same type of displacement, namely downthrow on the west side. Thus, in the southern part of the Sacramento Mountains the strata are uplifted along two fault zones, and there is an asymmetrical trough formed by the back slope of the lower fault block and the steep escarpment of the higher one.

The capping rock over most of the range is the San Andres limestone (Permian—Guadalupe), which ranges in thickness from a feather edge to a maximum of 700 ft. The San Andres is underlain by less resistant mudstone, gypsum, and thin-bedded limestone of the Yeso formation (Permian—Leonard), 1,200 to 1,800 ft thick, and this in turn by redbeds of the Abo formation (Permian—Wolfcamp) and successively older strata down to Precambrian(?). The strata dip eastward at about 100 ft per mile.

The stratigraphy and structure of the Sacramento Mountain front have been summarized by Pray (1954).

TOPOGRAPHY

The escarpment that faces the Tularosa Basin has been much dissected by streams in short steep canyons. In the northern and central part of the range, these streams are actively shifting the divide eastward, at the expense of streams flowing down the long gentle back slope of the mountains to the Pecos River some 80 miles to the east. In the southern part, a three-way drainage system has developed (fig. 2), owing to the structural trough in front of the Sacramento River fault zone. The components of this three-way system are (1) the short, steep-gradient streams, such as Grapevine Canyon and its tributaries, that flow into

the Tularosa Basin and end on alluvial fans; (2) the Sacramento River, flowing southeastward and also ending on an alluvial fan; and (3) the upper reaches of many streams that flow eastward to the Pecos River.

All these, including the Sacramento "River," are ephemeral streams. The present climate is semi-arid; average annual precipitation at Cloudcroft is 22.0 in., and that at Alamogordo is 10.5 in. Spring runoff from melting snow may put some water into stream channels over most of the range, and summer rainstorms may produce heavy discharge locally and temporarily. For the sake of brevity,

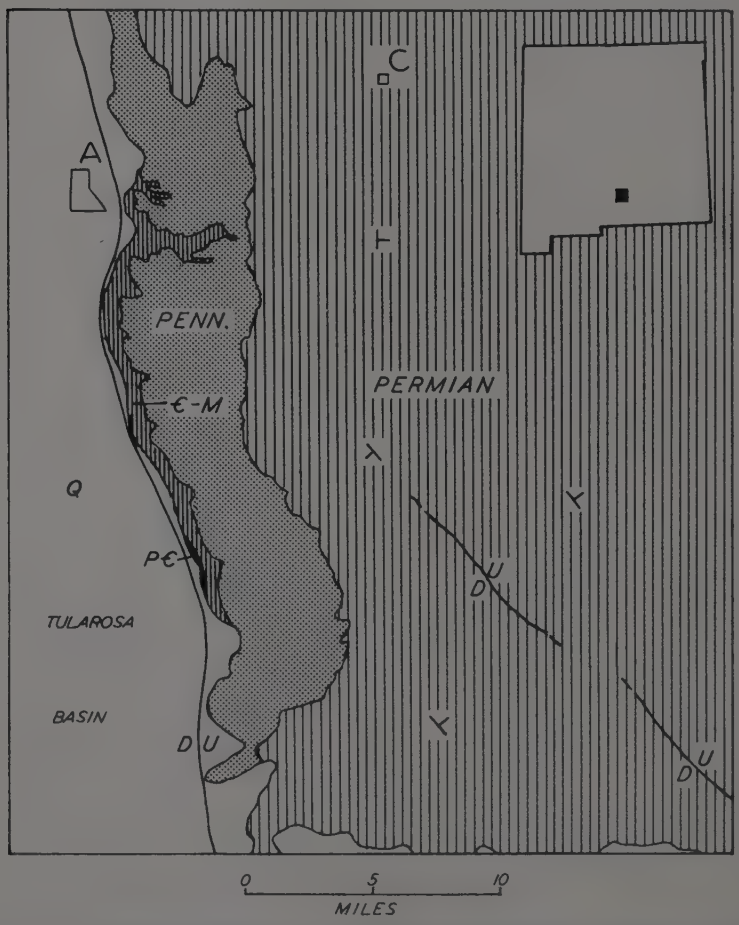

FIGURE 1. Generalized geologic map of the Sacramento Mountains, New Mexico. Elevation of Cloudcroft (C) at crest of the range is 8,650 ft; that of Alamogordo (A) is 4,300 ft.

in this paper a term such as "Grapevine Canyon" is used to refer both to the canyon and to the ephemeral stream that flows in it.

A drainage map of the southern part of the range (fig. 3) shows the extent to which the three components of the drainage are out of adjustment. Tributaries entering the Sacramento River from the west are being captured by streams flowing into the Tularosa Basin, and indeed at places the main river channel itself is threatened. Eastern tributaries of the Sacramento, on the other hand, are growing by capture of the headwaters of Pecos River drainage. The asymmetry of the Sacramento River valley is shown on the profile, figure 4.

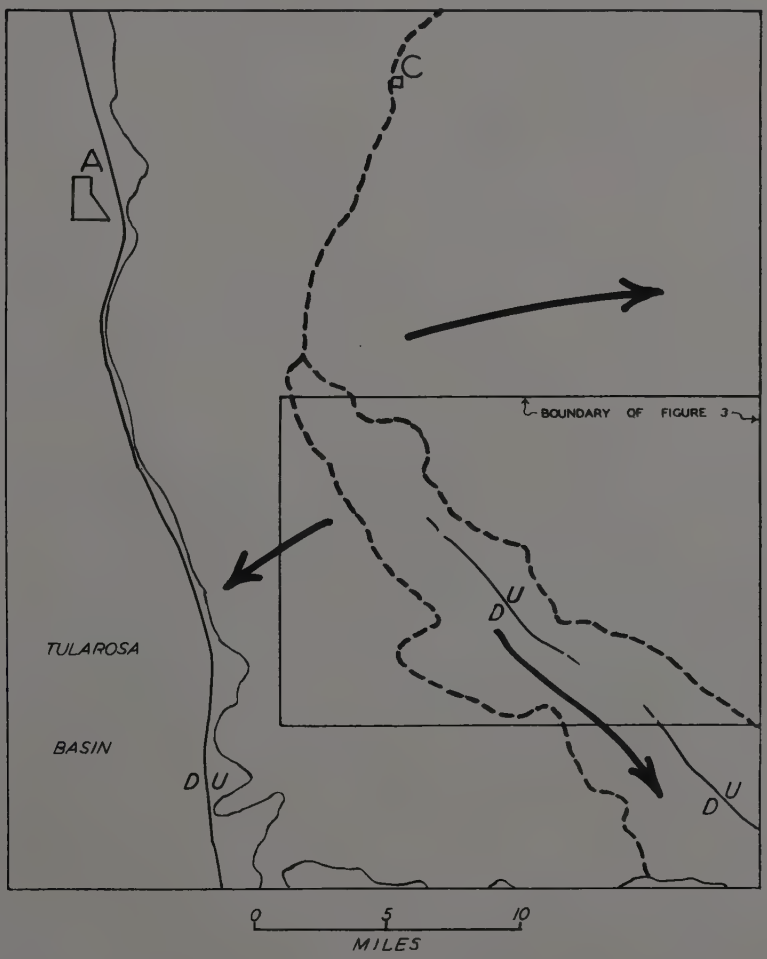

FIGURE 2. Three-way drainage pattern of the Sacramento Mountains. Dashed lines are divides.

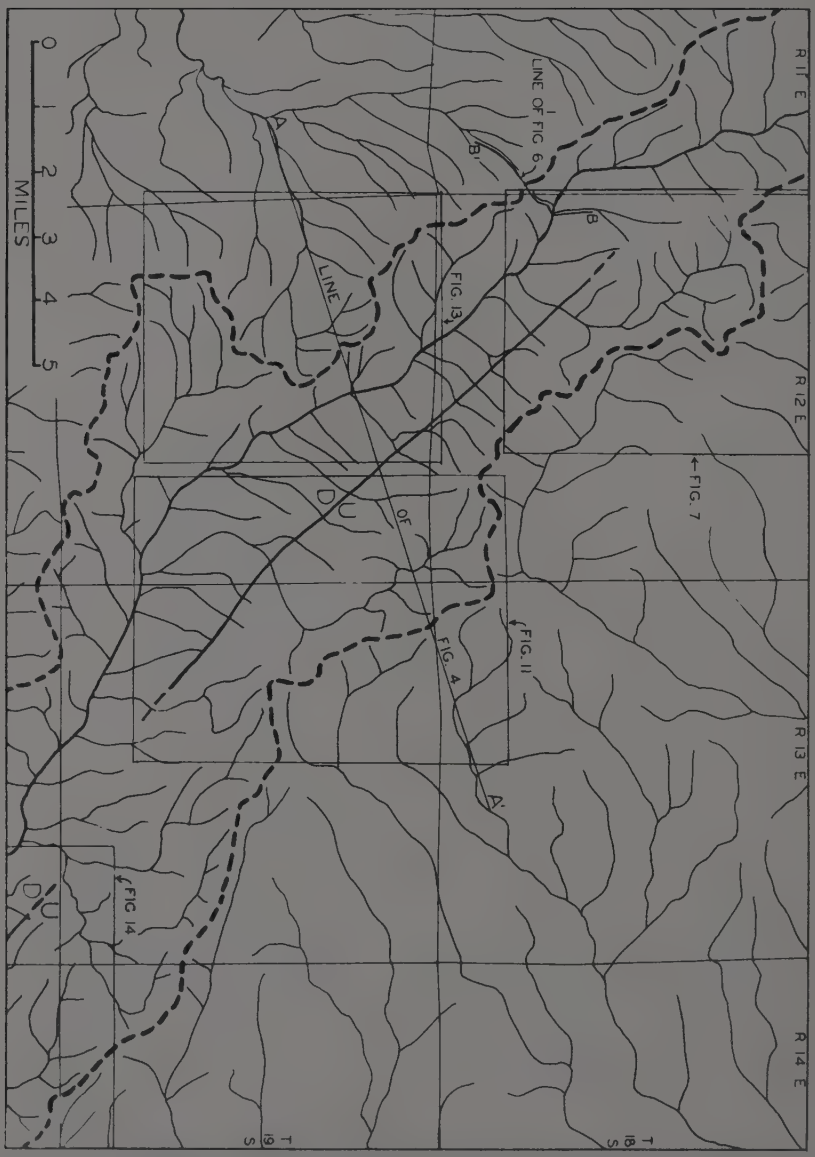

FIGURE 3. Drainage and index map, southern Sacramento Mountains. See figure 2 for location of the area.

MAP AND PHOTOGRAPH COVERAGE

Most of the area considered lies within the Sacramento Division of the Lincoln National Forest, for which a modern topographic contour map is available. In addition, the eastern part of the area is covered by air photographs made by the Soil Conservation Service in 1941 and 1942. The photo coverage extends for some distance south of the mapped area. No controlled photo-mosaics or large-scale geologic maps are known to me. The area is shown on a recent preliminary geologic map of southeastern New Mexico (Dane and Bachman, 1958), on a scale of one inch to about 6 miles.

DRAINAGE DEVELOPMENT

Grapevine Canyon—Sacramento River

Capture of the upper course of the Sacramento River by tributaries of Grapevine Canyon is imminent. Maps and air photographs of the divide show that

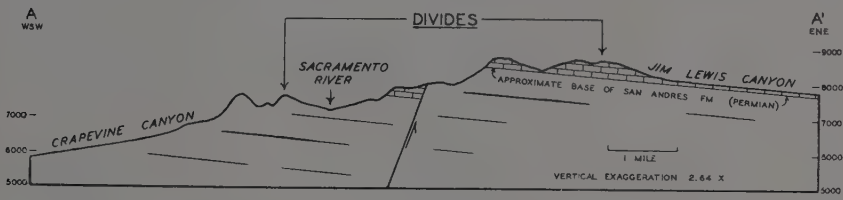

FIGURE 4. Profile, southern Sacramento Mountains, along line A–A', figure 3. Note asymmetry of the Sacramento River valley.

FIGURE 5. View southeastward along escarpment in sec. 25, T. 18 S., R. 11 E., near where West Side Road crosses the divide. Steep slope, underlain by soft rocks of Yeso formation, drains west into Grapevine Canyon. Skyline to left of center marks approximate dip slope on the San Andres limestone, draining into Sacramento River.

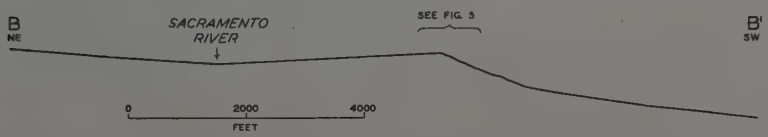

FIGURE 6. Profile along line B–B', figure 3. Horizontal and vertical scales are the same. By headward erosion, tributaries of Grapevine Canyon on the right will eventually reach and divert the Sacramento River.

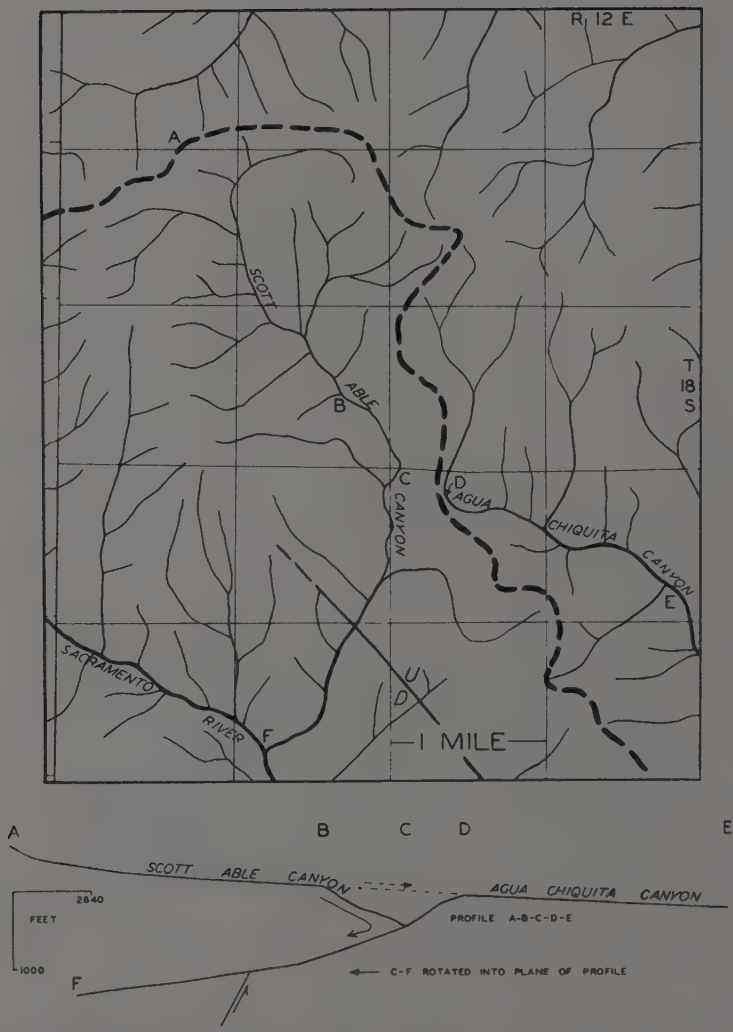

FIGURE 7. Recent beheading of Agua Chiquita Canyon by Scott Able Canyon. See figure 3 for location of the area. Photographs shown in figures 8, 9, and 10 were taken at point D on the map.

FIGURE 8. View southeast down the floor of Agua Chiquita Canyon at point D on figure 7. This is typical of the valleys that drain eastward to the Pecos River.

FIGURE 9. View southwest, from same point as figure 8, down Scott Able Canyon. In foreground is floor of beheaded Agua Chiquita Canyon, with gravel of San Andres limestone, the bedrock formation.

FIGURE 10. View northwest, up Scott Able Canyon, from a point a few feet west of where figures 8 and 9 were taken.

capture will first occur in the southeastern part of T. 18 S., R. 11 E. (fig. 3), where the divide is only 0.7 mile horizontally and 200 ft vertically from the bed of the river. A photograph of the escarpment at this place is given in figure 5, and a profile in figure 6. Since Grapevine Canyon falls more than 600 ft in the first mile west of the divide, and is eroding weak rocks of the Yeso formation, rapid headward encroachment to the river channel is inevitable. Although the river is under attack from west-flowing streams at other places along its course, nowhere else is the stage set for such early action.

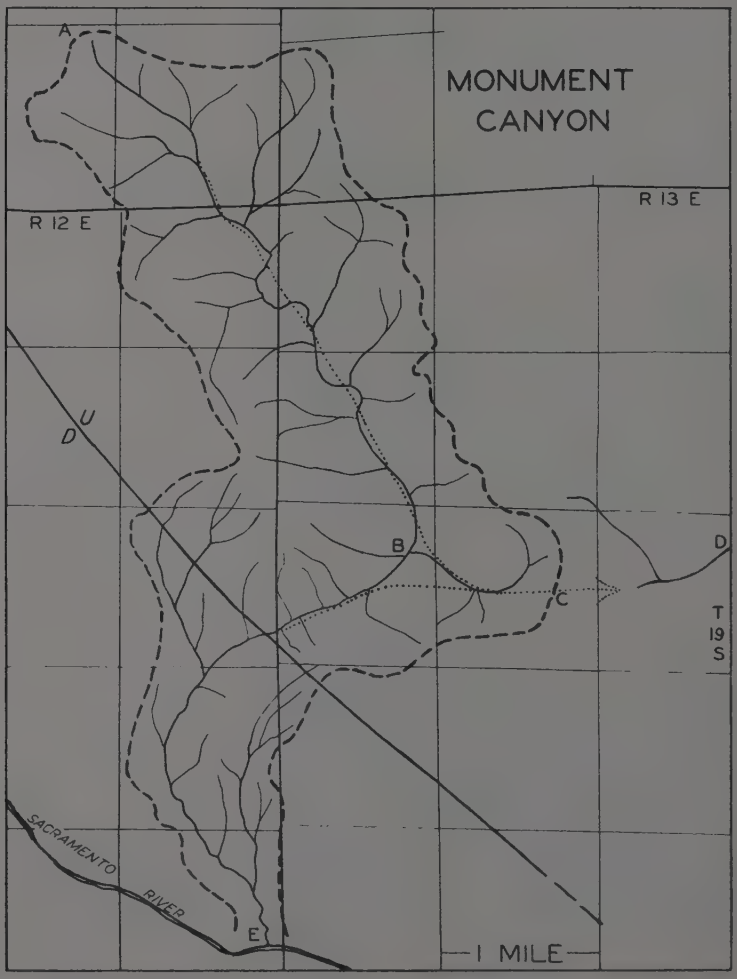

FIGURE 11. Drainage basin of Monument Canyon. Dotted lines show approximate course before capture. Letters refer to the profile, figure 12. See figure 3 for location of the area.

Unlike many parts of the southern Sacramento Mountains, the locality mentioned above is readily reached by car. A gravel road, known as the West Side Road, which follows a tortuous route from near Cloudcroft southward along the mountain front for many miles, climbs the escarpment here and crosses the divide into the Sacramento River valley.

Scott Able Canyon—Agua Chiquita Canyon

The type of diversion predicted above has already occurred at a number of places. The most striking example, because the most recent, is the interception of Agua Chiquita Canyon by Scott Able Canyon, a tributary of the Sacramento River (fig. 7). Here, as elsewhere, downcutting by the capturing stream has been facilitated because it is eroding in soft rocks of the Yeso formation, below a thin capping of San Andres limestone on which the captured stream takes its course.

The recency of this event is shown by the concordance between the long profile of upper Scott Able Canyon and that of Agua Chiquita Canyon (fig. 7), and also by the field relations. A natural vantage point is the jumping-off place where the present divide crosses the floor of Agua Chiquita Canyon some 400 ft above the elbow of capture. (This point can be reached by a primitive Forest Service road.) To the southeast, one views the wide gently sloping canyon of the beheaded stream (fig. 8). Turning to the southwest, one looks out over the gorge of Scott Able Canyon (fig. 9). By moving a few feet out to the very rim,

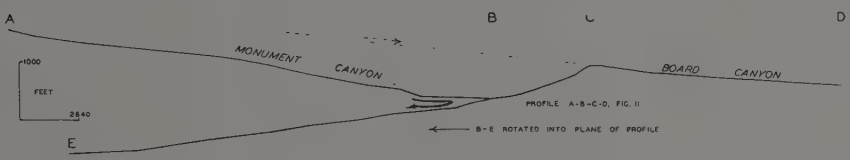

FIGURE 12. Beheading of Board Canyon by Monument Canyon. See map, figure 11, for letters locating profile.

one may then look upstream into that part of Scott Able Canyon that has a gradient of nearly 1,000 ft per mile (fig. 10). A more remarkable example of just-completed stream diversion would be hard to find.

Monument Canyon—Board Canyon

Monument Canyon, the next major stream course to the southeast, has had a similar history, although capture evidently occurred less recently. A map of its drainage basin (fig. 11) shows that the upper three-fifths of the present Monument Canyon formerly constituted the headwaters of Board Canyon, a stream of gentle gradient flowing eastward toward the Pecos River. The capturing stream has had time to steepen the gradient of the diverted segment of Board Canyon (fig. 12), and also to push back the divide east of the elbow of capture. The hooked stream pattern in sec. 17, T. 19 S., R. 13 E., suggests that the west-flowing tributary of Monument Canyon is now capturing and reversing the main channel of Board Canyon, barbing its tributaries.

Grapevine Canyon—Arkansas Canyon

A sequence of events markedly similar to that just described is shown by map and profile (fig. 13) to have occurred along the lower escarpment, southwest of the Sacramento River. Arkansas Canyon, a tributary of the river, has been beheaded by Grapevine Canyon, and the ensuing time has been long enough to allow the latter to deepen the valley of the captured stream for more than a mile above the elbow of capture.

In this area the headwaters of Grapevine Canyon are as close to the main channel of the Sacramento River as they are in T. 18 S., R. 11 E., described in an earlier paragraph. Here, however, the gradient of Grapevine Canyon is less

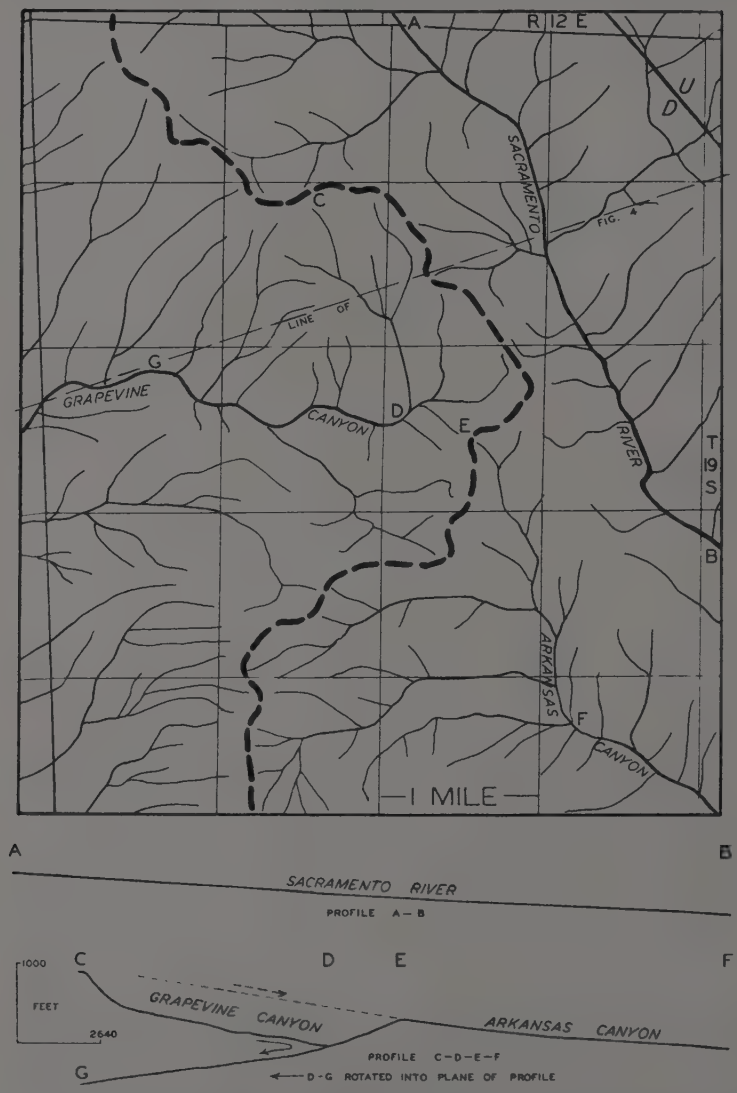

FIGURE 13. Beheading of Arkansas Canyon by Grapevine Canyon, and headward encroachment of the latter toward channel of the Sacramento River. See figure 3 for location of the area.

steep, and capture of the main stream will probably be deferred until after it has taken place in the other area.

The beheading of Arkansas Canyon can be taken as a preview of events to come for the Sacramento River.

Surveyors Canyon

In the southeastern part of the area shown on figure 3, and for some distance farther southeast beyond map control, there is a series of canyons that show a somewhat different history. Typical is Surveyors Canyon (fig. 14), a high-gradient tributary of the Sacramento River which has worked headward across the Sacramento River fault zone and diverted a stream system that formerly flowed east. Diversion has been accomplished by the wholesale reversal of the former stream course, with production of a notable set of barbed tributaries. It was while doing plane-table work in the Surveyors Canyon area that I first became aware of the anomalous stream patterns to be encountered in the southern Sacramentos.

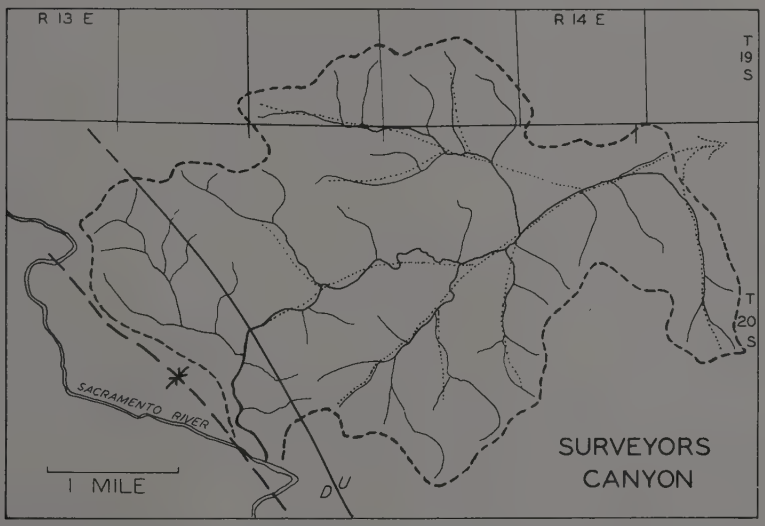

FIGURE 14. Drainage basin of Surveyors Canyon. Dotted lines show approximate course before reversal. See figure 3 for location of the area. The part lying in T. 20 S. has been traced from air-photograph contact prints.

Probably this type of diversion resulted from the fact that the stream to be captured was flowing almost directly away from the capturing stream, rather than at a pronounced angle to it. In this back-to-back relationship, the advantage was with the steep-gradient tributary of the Sacramento River.

EVOLUTION OF THE DRAINAGE

The present drainage pattern of the southern Sacramento Mountains is clearly structure-controlled. The streams are where they are because of uplift along the normal-fault zones and concurrent tilting of the strata. The anomalous stream patterns, and the youthful stage of development of the canyons, show that the streams have made only a start toward adjustment to structure.

Yet surely there could be few geologic situations in which stream adjustment could proceed faster than here. Not only do the potential capturing streams have the advantage of steep gradients, but they are eroding in weakly resistant rocks; while their prey, the Sacramento River and the east-flowing streams on the back slope of the range, are flowing on a thin veneer of San Andres limestone which is vulnerable to erosive attack along sharp divides. That even under these circumstances the drainage system is still so far from equilibrium strongly suggests that it is of very recent origin.

Two additional lines of evidence, one geomorphic and the other structual, support this conclusion. According to Pray (1954, p. 105), the Sacramento Mountains are bevelled by a widespread surface of erosion or summit peneplain. As evidence of the youthfulness of this surface, Pray and Allen (1956) cite the discovery of a small Cretaceous outlier at the crest of the northern part of the range. The strata of this outlier are about 200 ft thick, carry a Dakota(?) fauna, and rest on the San Andres limestone. They dip about 10 degrees, and lie well below the restored level of the summit peneplain. Thus, the latter must be post-Dakota. Pray and Allen conclude that it is Cenozoic, probably late Cenozoic.

Regional structural and stratigraphic evidence indicates that the normal faulting of the range took place during the Cenozoic, as did that in the other block mountains of the Basin and Range province. Indeed, little fault scarps that cut the alluvial fans along the west base of the range show that faulting has continued essentially to the present. Thus, it seems quite clear that peneplanation, uplift, and drainage development are all very recent events, probably occurring entirely in the late Cenozoic.

The general pattern of future evolution seems plain. The Sacramento River will be diverted to the west, and the lower escarpment will cease to exist as a major divide. All drainage will flow either west into the Tularosa Basin or eastward to the Pecos River. Although the west-flowing streams will be aggrading their lower courses by the further build-up of alluvial fans, still they will have steeper gradients than their opposite numbers for a long time to come. Hence the remaining divide will be shifted eastward, and the mountain profile will gradually approach symmetry. Any renewed uplift on the faults of the range will increase the gradients of all the streams, speed up the removal of the thin capping sheet of San Andres limestone, help obliterate the Sacramento River valley, and aid in establishing a bilateral system of drainage.

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Dexter (1954) clearly outlined the distribution of *Zapus hudsonius* in Ohio, his distributional map showing a preponderance of captures from the northeastern part of the state. As Dexter has intimated, there is little doubt that this reflects a greater amount of collecting in this part of Ohio rather than a scarcity of jumping mice throughout the rest of Ohio, so that any records from the southern and western part of the state become important. On October 1, 1960, my son and I captured an adult female *Zapus hudsonius* in a dead trap at the edge of a fallow corn field six miles east of Lebanon, in Turtle Creek Township, Warren County, Ohio. As far as I can determine, this is the first definite trap record for the jumping mouse in Warren County and the southwestern-most record for this mouse in the state. The one specimen previously reported from Warren County by Dexter was one which I secured from a taxidermist, Mr. C. Foxbower. This specimen is now in the University of Cincinnati collection. The circumstances surrounding the capture of the Foxbower specimen were rather obscure. Mr. Foxbower relates that a relative of his caught the mouse by hand while he was harvesting grain. A freight train was on a siding about one thousand yards away from the site of capture, and it was assumed that the animal had been transported to the area in one of the box cars. The present record suggests that *Zapus* is well established in Warren County since there is little possibility that the animal could have been transported into the trapping area. It might not be abundant, however, because on a number of nights of trapping, I and several other collectors in the counties immediately bordering Warren County to the south have failed to capture a single jumping mouse. It might also be of interest to note that on the night of the present capture the temperature dropped to 44°F, and that several different mammals taken along the same trap line had light coverings of frost on their fur. *Zapus* is usually reported to have one of the longest hibernating periods among the small mammals, although Hall and Kelson (1959) report that they may occasionally be found above ground in midwinter.

Following the latest revision of the group (Krutzsch, 1954), the present specimen belongs to the subspecies *Zapus hudsonius americanus* (Barton), as do all Ohio specimens. Its measurements are: total length, 193 mm; tail length, 115 mm; right hind foot, 30 mm; ear, 12 mm; weight, 12.3 g. The animal was not pregnant, and there were no signs of earlier pregnancy. The skin and complete skeleton (No. 1065) are deposited in the University of Cincinnati mammal collection.

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